DRAFT REPORT

VIRGIN RIVER RESTORATION

An evaluation of alternatives with focus on the potential to regenerate cottonwood (*Populus fremontii*) along the North Fork of the Virgin River in Zion National Park

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EXECUTIVE SUMMARY

The cottonwood forest has been documented to be declining within Zion Canyon in Zion National Park. Very limited successful cottonwood regeneration has occurred in recent years along the North Fork of the Virgin River and the majority of the extant cottonwood trees are older, disease prone, and vulnerable individuals. This report suggests that the potential for successful cottonwood regeneration may be limited by current climate and geomorphic conditions of the Virgin River and competition from native and exotic plant species. However, there is considerable opportunity to restore floodplain processes along the lower stream reaches that are currently channelized by wire and rock revetments. Cottonwood recruitment is limited to a relatively narrow riparian ribbon along the Virgin River and, potentially, its small tributaries.

The regeneration events that produced the cottonwood forest that currently covers the floor of Zion Canyon were facilitated by high water and sediment conditions in the Virgin River during the late 1800's and early 1900's and, to a lesser degree, in the mid-1900's. These conditions created wide, braided stream channel with a multitude of shallow channel and resulted in extensive overbank flooding and alluvial deposition. Historic photographs and descriptions document these conditions. This sequence of events created optimum conditions of seed dispersal, soil moisture, and scour protection for successful cottonwood recruitment. The extensive mature cottonwood forest within Zion Canyon is the result of these conditions and the regeneration of the cottonwoods that now blanket the valley floor will only occur when the region experiences a return to the moister climatic conditions that characterized that period.

The Virgin River today is a single thread channel with relatively stable, well-vegetated stream banks. Prior channel deepening has limited access to broad floodplains during moderate, frequent flow events. Channel morphology suggests low sediment loads. Narrow floodplains limit the extent of soil conditions suitable for germination and proximity to the stream channel increases the risk of subsequent scour. Observations also suggest North Fork cottonwood recruitment may be limited by the presence of competing vegetation including exotic graminoids and shrubs, by beaver/deer herbivory, and because of competing trees species have more efficient invasion strategies than cottonwood under the current fluvial and vegetation conditions in the park.

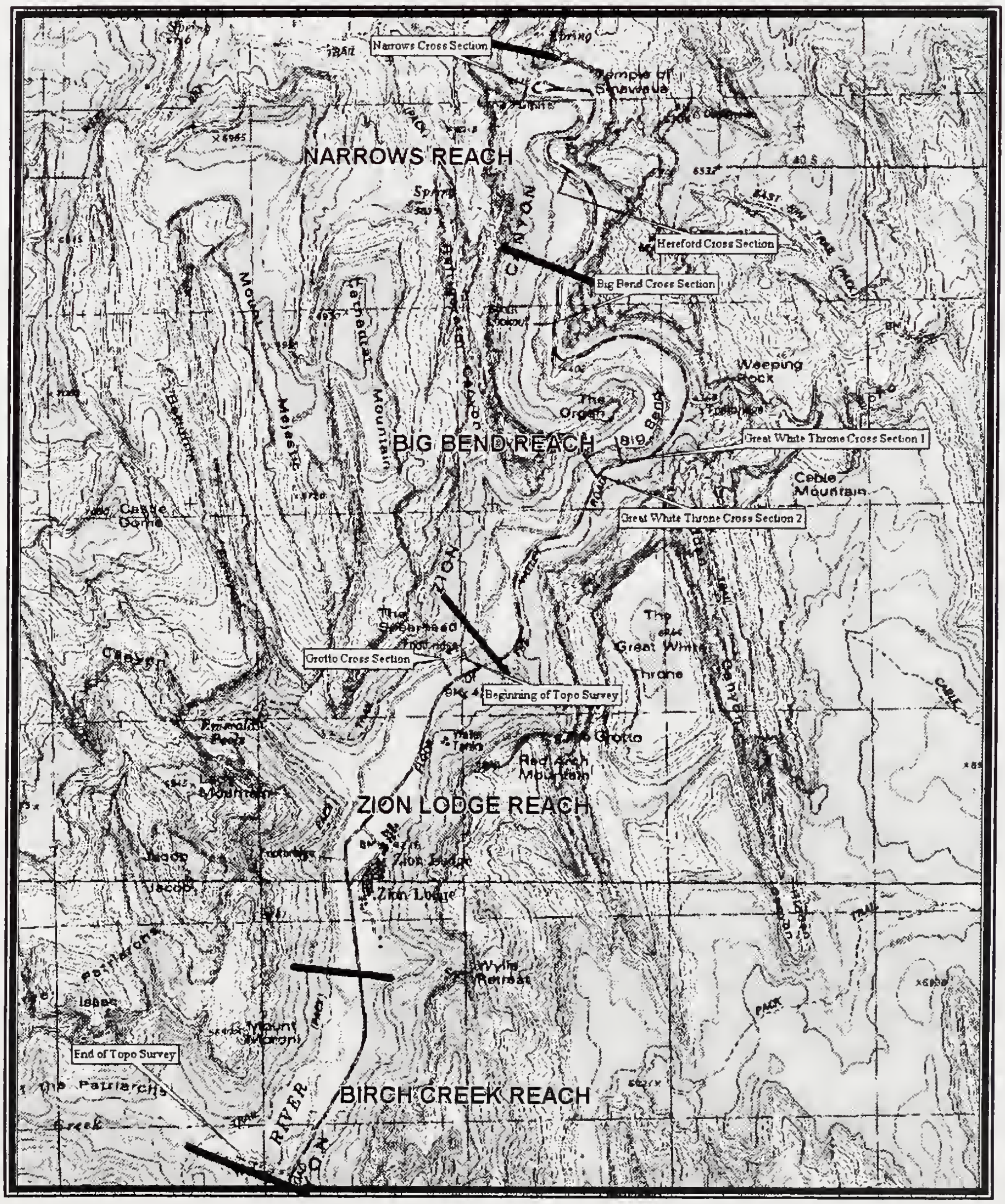
Successful cottonwood recruitment currently takes place in those stream reaches that have adequate floodplain width and the ability to meander. Germination is dependent on moist soil conditions in secondary channels and depressions along the adjacent floodplain. Recruitment is limited by available bare substrate and subsequent stream scour. In those areas where channel dynamics are constrained by natural (geologic) or man-made (revetments). However, there is significant opportunity to improve current recruitment rates especially along the channelized reaches in the lower canyon.

This report analyzes a set of alternatives for removing existing revetments along this reach and presents a set of actions to improve riparian function and cottonwood recruitment to be discussed at an April technical workshop in the Park.

INTRODUCTION

This project was initiated because of the concern that for the riparian function of the Virgin River within Zion National Park (Figure 1). Previous studies have documented that the number and distribution of cottonwood trees, a key indicator of riparian function, appear to be declining in Zion Canyon. The concern for this and other potential changes in woody plants stems from their important role in the ecological system, and because they contribute to the aesthetics and experience of the 2.3 million annual visitors to the park.

FIGURE 1. Map of Zion Canyon and project reaches



BACKGROUND

The North Fork of the Virgin River was aggressively channelized in the 1920's and 1930's in order to protect the newly constructed Zion Lodge. The stream was confined to the western-most portion of the 1,000-foot wide floodplain by excavating the channel deeper and by building a levee along the eastern side of the channel for about 4 miles. Over the years, the upstream half of the channelization has been washed out by the river, leaving the better-constructed and maintained levees in the vicinity of the lodge. These are armored with gabions (heavy wire baskets filled with rock) for much of their length. Though the wires along the bottom of many of the gabions have rusted away, the levees have been periodically repaired, and remain effective in isolating the river from the floodplain, even when large floods have occurred (a 100-year event of 9,100 cfs).

The negative consequences of this channelization are that the channel no longer maintains natural patterns of flooding and channel migration. As the greatest mechanism of natural change in the valley, disruption of river processes sent ripples through all of the physical and biological processes there. One of the most apparent is the lack of reproduction among cottonwoods and other riparian trees. Little if any reproduction of these species is occurring, and the older overstory is decadent and rapidly dying out. Some channels of ephemeral tributaries are blocked from direct discharge into the river by the levees, so their more indirect pathways create sediment traps that require frequent cleaning.

One of the most compelling reasons for restoring the channel is that the levees are no longer the only, or even best, source of flood protection for the lodge. The park road, with improvements done to it over the years, is at a higher elevation than the levees, so will provide protection for the lodge and other facilities during larger flood events.

PROJECT TASKS AND OBJECTIVES

Formal tasks within this project include:

1) Collection of essential baseline information about the resources and structures in the Virgin River floodplain,
2) Preparation of a concept restoration plan including evaluation of the preliminary alternatives, and
3) Conducting a workshop with Park staff, interested agencies, and knowledgeable professionals to discuss and critique the concept plan.

The primary objective of the project is to collect data necessary to prepare a concept plan for restoration of the natural form and function of the North Fork of the Virgin River within Zion National Park. The project site includes approximately 4 miles of the North Virgin River between the mouth of the Virgin River Narrows and a prehistoric landslide. The concept plan will be based on an assessment of the current channel and identify design restoration criteria. Based on these criteria, an evaluation of 6 preliminary alternatives developed by Zion National Park will provide the basis for a concept restoration plan. The plan will provide some of the data necessary to develop an Environmental Assessment and to seek funding sources for construction of the project.

At least two evaluations of the prospects for restoring this reach of the river have been conducted, Weiner and Smillie (1997) and Smillie et. al. (1997). From these, and evaluations by park staff, six options have been identified for restoring the river channel.

1) **Remove Levees and Construct Channel with Natural Characteristics** - The levees would be removed and a channel would be physically constructed for the entire 1.5-mile reach, with dimensions and patterns similar to natural conditions and consistent with a channel in equilibrium
2) **Remove Levees** - The levee material and rock filling the gabions would be removed and deposited in the channel to raise the streambed or disposed of elsewhere.
3) **Breach Levees and Construct Selected Meanders** - Wire would be entirely removed, the levees physically breached in a few places and 2-4 meanders constructed outside of the levees to hasten lateral movement of the channel.
4) **Remove Wire Only** - The wire would be removed from the gabions to hasten the river's actions and reduce hazards.
5) **Benign Neglect** - Allow the gabions to deteriorate and the river to slowly remove the levees.
6) **Retain Levees** - The levees would be maintained for the foreseeable future. This would require repair and some replacement of gabions.

METHODS

This study was initiated to understand the following questions and attempt to understand if the following goals can be achieved:

1. Is the evidence available and do the data suggest that cottonwood is declining in the park.
2. Is a shift in woody vegetation occurring that would further exacerbate any decline in cottonwood that may be occurring in the park?
3. What appear to be the causative agents that may be contributing to a cottonwood decline and other woody vegetation shifts.
4. What causative agents, if any, can be influenced through restoration and management to address changes that may be occurring.
5. What types of ecological restoration strategies could be used for both regenerating cottonwood and for reversing vegetation shifts that may also be discouraging the regeneration of cottonwood?
6. Is the current riparian and valley bottom vegetation community representative current hydrologic and geomorphic conditions, and is this landscape a practical objective without repeated plantings and other manipulation?
7. Identify data gaps and additional data needs to understand the above issues.
8. Identify potential testing, demonstration projects, and research and monitoring needs to understand restoration potentials.

This report was generated using limited literature review, limited field reconnaissance, and discussion with other project team members present during the field reconnaissance.

As a team we reconnoitered the cottonwood and fluvial systems within the park. Cross-section and longitudinal profile surveys were conducted at 6 sites along the North and East Forks of the Virgin River to characterize the physical character of the channel, floodplain and terraces. Bed and bank material was characterized using the Wolman pebble count. At these and other sites we visually examined the existing cottonwoods and did reconnaissance examinations for seedlings, sapling, and mature canopy trees. In addition, we increment cored some representative trees within some of the cross-sectioned areas. These increment core specimens were then mounted, sanded, and ages of the trees were determined.

We used this information for drawing preliminary interpretations of the conditions within the riverine environment that were conducive to cottonwood regeneration, non-supportive of regeneration, and settings conducive to regeneration of other woody plant species. General notes and photographs about the field conditions were also taken.

A set of basic assumptions and information derived from information gathered previously and in this study was used to develop a preliminary model to help understand cottonwood regeneration and fluvial processes in the park. That work on the STELLA model is contained in Attachment 1.

SUMMARY OF PREVIOUS STUDIES

Much relevant study has been conducted within the park. This report does not provide a critical review or detail summary of the large body of literature on this subject, but instead attempts to briefly and pointedly summarize relevant points from some key research projects.

STEEN, 1999

This thesis has documented the following:

1. Manipulation of the stream environment, including the installation of stream bank revetments, land-filling, stream channelization, and other localized drainage and routing of perimeter waters to the stream have occurred since at least the period of National Park Service occupancy and stewardship of the Park a situation aggravated by confinement of portions of the channel in levees.

2. Manipulation of the uplands, the stream, and drainage infrastructure, and vegetation – especially woody vegetation reduction for fuel wood and other uses, occurred at the time of settlement and probably up and to the period of National Park Service occupancy. Denudation of woody vegetation was believed to have occurred during this period from approximately 1860's to the turn of the century. During this period, larger terrace areas were used extensively for agricultural production and at a point(s) in time these fields were fallowed and have been invaded by woody and herbaceous vegetation.

3. Planting and landscaping of the park and restructuring of the stream environment occurred, yet little or no records are available on actually what and where plantings occurred. This information may be presently available.

4. Prehistory of the site suggested Native American occupancy, and this likely had significant influence on vegetation, including conversion of some terraces to agricultural land-uses and other uses.
5. Late 1800's settlement and potential associated significant erosion and depositional processes that were regional in scale and may have been caused by overgrazing, climate change, deforestation, and perhaps other variables.

HEREFORD , JACOBY, AND MCCORD, 1995

1. The floor of Zion Canyon can be divided into a series of alluvial features representing different periods of the fluvial system. These terraces are Prehistoric (pre-900 -1200 AD). Settlement (>1200-1883), Historic (1892--~1926), Early Modern (1930-1940), Modern (1940-1970), and the active channel/floodplain.

2. Erosion and deposition were largely contemporaneous with variations in streamflow. Erosion was during unusually high streamflow and deposition during relatively low streamflow.

3. Precipitation and runoff immediately before and during the historic arroyo cutting period near the turn of the century were the most unusual in 300 years.

4. Tree ages are reported from the Historic and Modern Terraces using estimated dates of establishment based on tree ring methods. Trees from the Historic Terrace are dated from 1893, 1895, 1900, 1904, 1907, 1909, and >1909. Trees from the Modern terrace are dated from 1940, 1947, 1951, 1953, 1957, and 1963.

Other documents have speculated on the effects of A) deer browse and B) beaver herbivory on cottonwood seedlings and saplings, and larger trees as having profound influence on cottonwoods ability to maintain populations of varying size and age classes within the park.

FIGURE 2. Summary of general relationships with fluvial aggradation and erosion processes (Hereford, et al, 1995).

Aggradation:

- Builds up channel and adjacent floodplains
- Channel widens and meander increases
- Sediment comes from upstream sources and eroding stream

Erosion:

- Channel bed lowers
- Channel widens and forms new floodplain at lower elevation
- Active floodplains become terraces removed from subsequent scour

Triggered and maintained by regional factors:

- Climate (long term)
- Landuse (historic period)
- Individual events or series of events

Mainstem deposits:

- Transported by Virgin River from upstream sources

←Interbedding→

Tributary deposits:

- Transported to alluvial valley by fluvial activity of tributary streams, gullies, rills, and debris and landslide

Channel, floodplain, terrace materials

- Yellowish-gray
- Poorly to moderate well sorted
- Fine to medium-grained sand and minor subrounded to rounded gravel
- Well bedded

RESULTS AND DISCUSSIONS

The widespread distribution of cottonwood trees throughout the western U.S. obscures the fact that successful recruitment requires a very special set of conditions. Seeds must be dispersed onto bare fine-grained substrates that have adequate moisture throughout the spring and summer for germination but is not subsequently scoured. In Zion Canyon cottonwood seeds are dispersed in very large numbers during April and May each year. Seed viability is measured in days rather than weeks or months and the vast majority of seeds never find moist soils in which to germinate. Of those that do sprout a large number do so in the wet substrate of the active channel and are subsequently scoured away in the next flow event.

As a result, channel fluvial processes and morphology play important roles in providing successful recruitment environments. In this paper the alluvial system is divided into 1) an active or bankfull channel, 2) an associated floodplain, and 3) assorted terrace features. The bankfull channel is defined as carrying moderate, frequent flow events (Leopold, 1994). The geomorphic floodplain is defined as a level feature, adjacent to and created by the stream in the current climate, and overtopped by moderate, frequent flow events. These moderate, frequent flow events generally have 1 to 2 year return intervals (Leopold, 1978; Moody, et.al., 1999). For this reach of the Virgin River bankfull discharge is estimated to be ~1100 cfs. Terraces are defined as abandoned floodplains. Bankfull stage was identified at several sites within Zion Canyon and provides a common reference point for assessing floodplain processes along the Virgin River.

Generally the floodplains and their associated features such as secondary channels and depressions create conditions for successful cottonwood recruitment. Sprouts in the active channel are scoured by subsequent flows while the terraces do not contain adequate soil moisture through the dry summer season. Bare substrate is generally created through floodplain scour, floodplain deposition, and/or channel meander.

Several delineative criteria were used to describe the physical channel characteristics. Bankfull width, mean depth, and maximum depth refer to dimensions of the channel at bankfull stage. Floodprone width is defined as the width of the floodplain at an elevation equal to twice maximum bankfull depth. Width-depth ratio is bankfull width divided by bankfull mean depth and is a dimensionless measure of channel shape. Because sediment transport is largely dependent on channel shape, width-depth ratio is also an indicator of this fluvial process. Entrenchment ratio is floodprone width divided by bankfull width and is a measure of the stream's ability to utilize an adjacent floodplain.

Stream Reaches within Zion Canyon

The North Fork of the Virgin River through Zion Canyon was divided into 4 reaches based on differing stream channel morphologies (Figure 1). These reaches are:

1) Narrows Reach; geologically controlled upper reaches
2) Big Bend Reach; unconstrained alluvial upper reaches
3) Zion Lodge Reach; channelized revetment reaches
4) Birch Creek Reach; lower meandering reaches

In addition, a site along the East Fork Virgin River was surveyed to compare with the North Fork sites.

The following section briefly summarizes key observations in these surveys. This information was then correlated with hydraulic data and tree age data to begin to formulate hypotheses on how cottonwood regeneration currently occurs in the park with an eye toward what restoration strategies and recommendations may be useful in the future management of cottonwood and the fluvial environments in Zion National Park.

SUMMARY OF REACH OBSERVATIONS

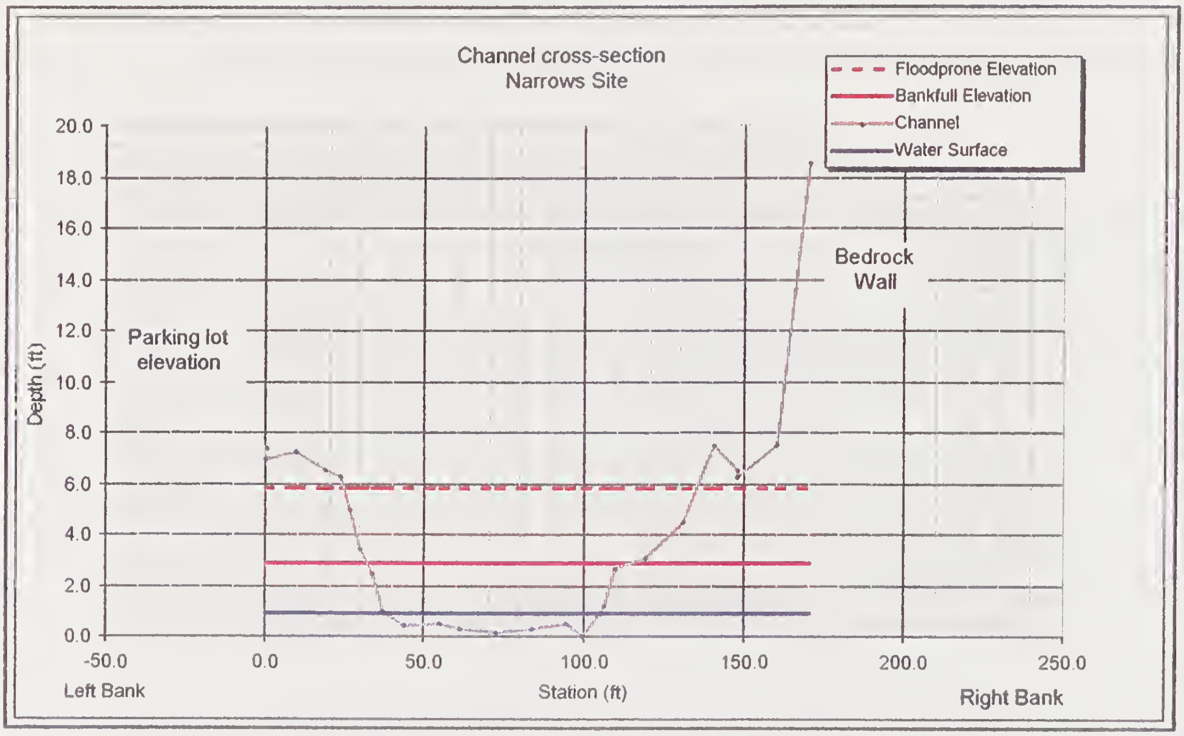
1. NARROWS REACH

This reach extends from the Narrows parking lot to a point just upstream of the viewpoint above Big Bend. The valley floor is relatively narrow within these reaches and the shape of the surrounding canyon geology controls the channel meander pattern. Revetments are common along the eastern bank where the channel is adjacent to the road. The channel is dominated by riffle sections, a low width-depth ratio, and has limited access to an adjacent floodplain. Channel bed appears to be partially cemented by fine clay particles. Banks consist of cohesive soils w/sand veneer. Channel bed is gravel/cobble with clay veneer, with sand in bed. There is little evidence of active erosion or deposition and bare substrate is at a minimum.

In these locations we believe relatively even-aged 100-year-old cottonwood isochrones dominated the outside and upper margins of the highest terraces. Only occasional scattered young cottonwood trees were found in other locations and all were on mid to lower terraces, growing on the side slopes and tops of the depositional strands that were located between the location of the bank full stage and the upper-most terrace. The high terraces are covered w/ grass and mature cottonwood, ash, and boxelder. Low point-bars are all well vegetated with sedge/rush, baccharis, grass woody seedlings. Cross-sections were surveyed at two sites (Figure 3).

The *Narrows survey site* lies just above the Temple of Sinawava parking area at the mouth of the Virgin Narrows (Figure 3). The channel is constrained by revetments along the left (road) bank and by stable terraces along the right bank. There is little or no floodplain. Stream banks are stable except along the constructed fill of the parking area. Most successful woody plants near the river appear to be in areas partially protected by geologic (boulders/bedrock) or geomorphic (point bars) features. There are numerous cottonwood and ash seedlings in the moist fine sediments of the bankfull channel and within 6-10 inches of the waterline. Several 10 – 20 foot cottonwoods and ash individuals are found on lower terraces. Baccharis (*Baccharis emoryi*) are dominant along bankfull stage; coyote willows (*Salix exigua*) are very sparse. Cool season grasses proliferate leaving little bare substrate.

FIGURE 3. Cross-section at Narrows survey site.



The *Hereford survey site* lies approximately 0.23 miles below the Narrows site and is within the Hereford, et.al. study area. Reach is straight, continuous run/riffle. Cross-section traverses several of Herefords terraces. Channel is relatively flat bottomed with a uniform trapezoidal shape. The left bank below road is armored with wire baskets of the newer vintage. Baccharis (*Baccharis emoryi*) is thick along riprap bank and only slightly less robust along right bank. Numerous ash seedlings along waterline and within bankfull channel; few cottonwoods are present and no willows. Scattered 10'-20' ash trees near bankfull stage on both banks. Bankfull features include a narrow depositional bar running along right bank composed of sand and stabilized by thick baccharis community. Sedge-rush community is continuous from water's edge to bankfull. Three terrace features described by Hereford (1995) lie within this cross-section. Descriptions of these features are described below and shown in Figure 4.

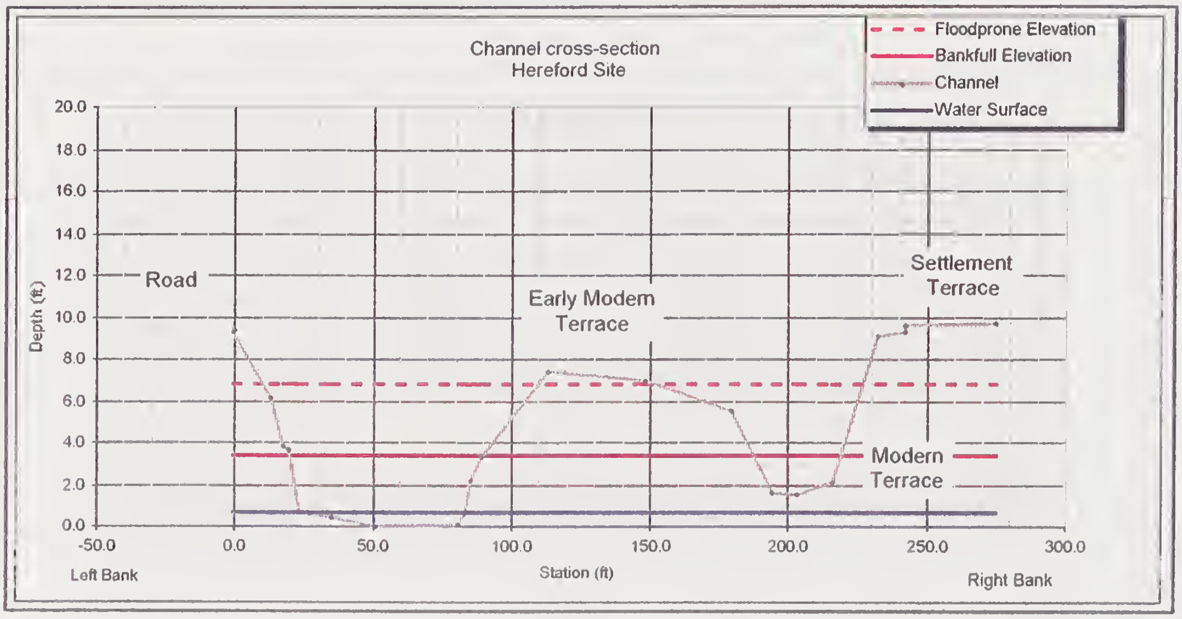
Modern Terrace (~1940 – 1970) lies approximately 1.5 feet above the current channel bed elevation. It has a sandy substrate and appears to be an abandoned or secondary channel. Cobbles are sometimes evident within channel and along margins. Young Ash trees (6'-10' tall) growing along margins. A single young juniper was also located within channel. This channel becomes active at about bankfull stage and the vegetation suggests moister soil conditions as it approaches the river downstream.

Early modern terrace (~1930 – 1940) lies approximately 7.0 feet above and adjacent to the present channel. It is composed of sand and colonized by grasses, occasional prickly pear

cactus and various annuals. Cryptogamic soils lie over much of the surface. There are scattered ash and cottonwood trees 20 – 30 feet tall.

Settlement Terrace (~1860 – 1890) lies approximately 10 feet above current channel bed elevation. Sands with bunch grasses and mature cottonwoods dominate the substrate. No young cottonwoods were observed on this terrace.

FIGURE 4. Cross-section at Hereford survey site



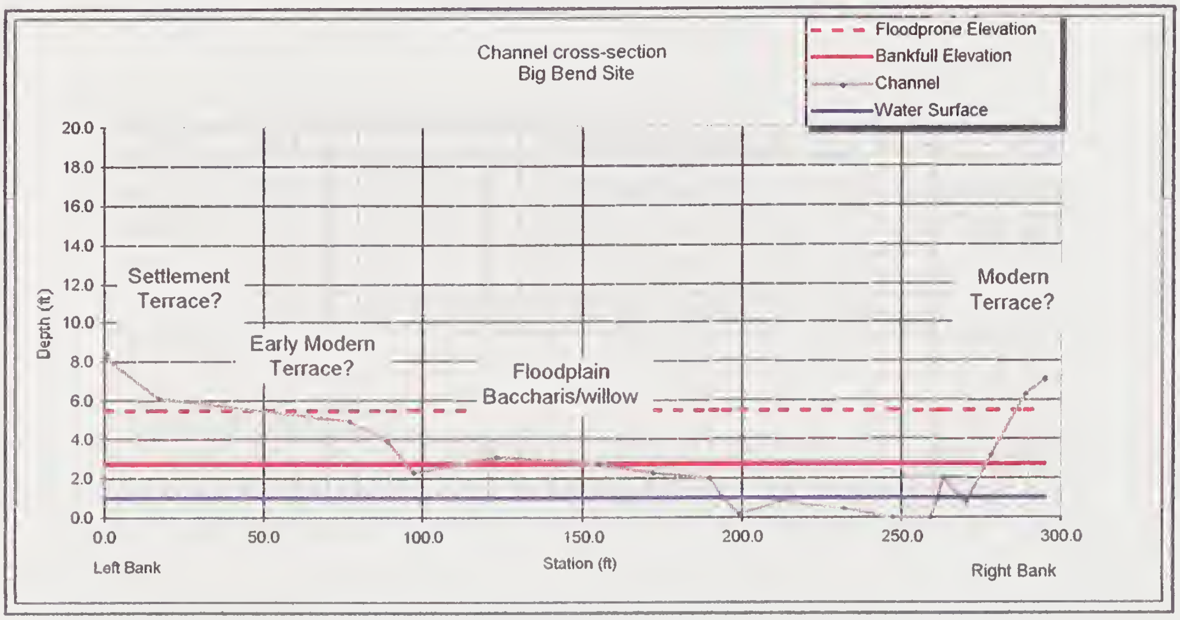
2. BIG BEND REACH

This reach begins below the Hereford Site and extends to the Grotto Campground footbridge. Although much of this reach was once channelized most of the revetments are gone or no longer constrain channel movement. The valley floor is relatively wide and the channel has some degree of movement. The reach is dominated by a series of riffle/run sections and has significantly more complex morphology. The stream is actively forming meanders and low cutbanks lie along both banks especially at outside of meanders. High terraces are restricted to valley margins. There is evidence of recently abandoned meanders that now serve as cut-off channels. At least some of these cutoff channels are active below bankfull creating mid-channel islands. Because the splits appear to be limited to two channels, the system is not considered braided. The bankfull channel is relatively wide with a high width-depth ratio. Mid-channel bars and secondary channels are common. Two sites were surveyed in this reach.

Big Bend survey site lies just upstream of the high viewpoint along the road just above Big Bend (Figure 5). The channel has a meandering riffle-run morphology with numerous low islands and cut-off channels. The combination of added sediment from eroding banks and split flow has formed a number of low unvegetated mid-channel bars.

There are several 10'-20' ash and cottonwood trees established within the floodplains or in the abandoned or cutoff channels. Ash are usually more common. Hundreds of small seedlings (ash and cottonwood) were observed on low, moist sandbars located within the bankfull channel. However these have very little chance for survival. Baccharis dominated the low terraces or floodplains but willow as well as tamarisk was much more common in this reach. Several Cottonwood individuals 10'-20' tall were observed along the floodplain and in abandoned channels.

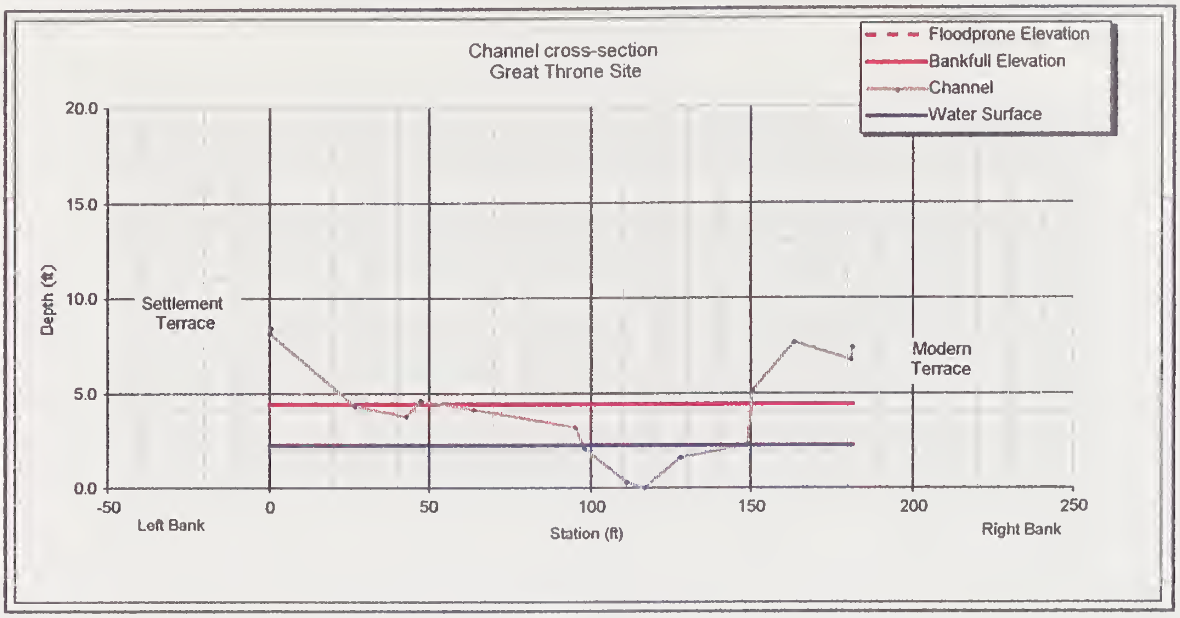
FIGURE 5. Cross-section at Big Bend survey site



Great White Throne Site is located just downstream of Big Bend. This reach has considerable width to meander. There is very little incision with high terraces only 6 feet above streambed (Figure 6). Below the upstream revetments the channel makes a series of low flow meanders with low alternating point bars. The bars are freshly disturbed with a surface of sand over gravel/cobble. Young 1-year seedlings are very numerous within the active channel; cottonwoods, baccharis, tamarisk, and ash but obviously few survive. It appears that the river may not mender much at bankfull or above.

Low terraces on both sides of river contain a reasonable number of 10'-25' ash, cottonwood, and tree willow. Coyote willow is also more abundant than at other sites. Low bars are often very wet and colonized by equisitum and sedges/rush. Arroyo willow (*Salix exigua*) is also more common. A survey of a single floodplain bar resulted in a count of 8-10 cottonwood, 25-30 ash, and 3-4 black willow. These individuals appear to be 5 – 10 years old. Recent beaver herbivory on cottonwoods and willows was observed at this site. Mature cottonwoods were abundant on the settlement terrace near the road.

FIGURE 6. Cross-section at Great White Throne survey site



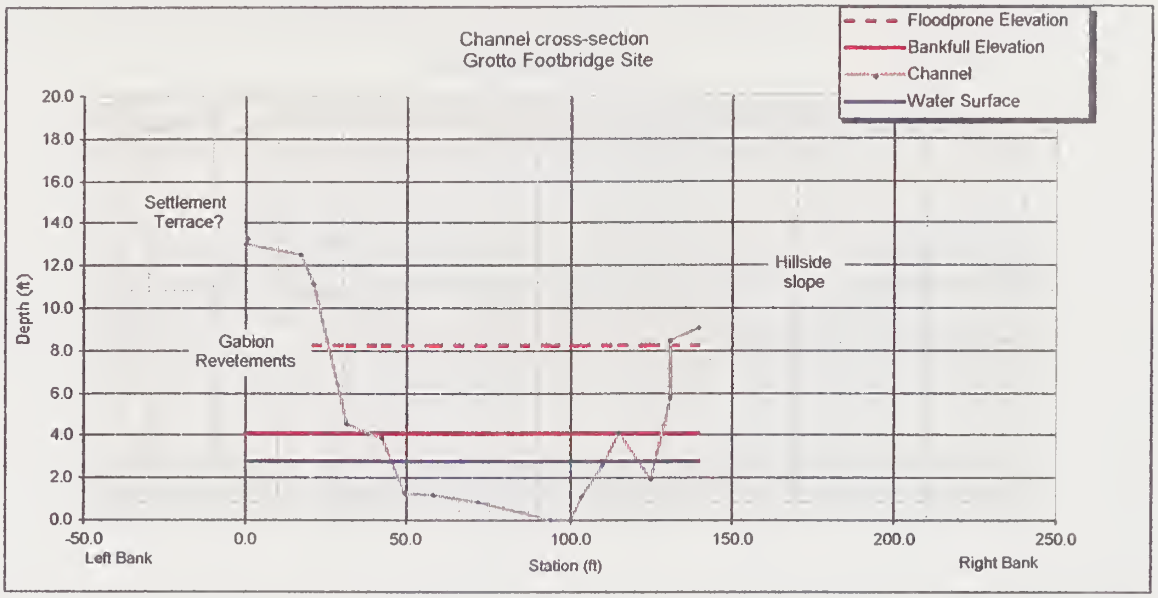
3. ZION LODGE REACH

This reach begins just above the Grotto Campground footbridge and extends through the straightened stream section below the Lodge footbridge. The entire reach had been channelized and constrained by wire covered rock riprap. In many areas the wire had deteriorated and the rock was falling into the channel. Channel is narrow with a uniform trapezoidal shape and no floodplain access. These reaches were zones of apparent and conspicuous regular scour and both the potential presence of moist and fine substrates for potential cottonwood invasion and cottonwood invasion were not observed.

The reach is stable in that there are no cutbanks, however it is deeply incised below high terrace. Both banks thickly vegetated primarily with *Baccharis emoryi* with a few *Salix exigua* and tamarisk. A sedge/rush community exists along water's edge. Cottonwood seedlings are numerous on very low bars well below bankfull but are unlikely to survive subsequent flows. Scattered juniper grow at elevation of right pin on desert slope. Absolutely no tree species observed along either bank.

Riprap baskets are reinforced around bridge but in other places rotted at bottom w/ rock spilling out. High terrace is very flat and sandy with a widely scattered mature cottonwood forest. These were once leveled and utilized as cultivated and irrigated fields. A single representative cross-section was surveyed in this reach just below the Grotto Campground footbridge (Figure 7).

FIGURE 7. Cross-section at Grotto footbridge survey site



4. <u>BIRCH CREEK REACH:</u>
This reach begins at the end of the straightened stream section below the Lodge foot bridges and extends to Birch Creek. Revetments are limited to the outside of those meanders that may impinge in the road or a parallel utility easement. From aerial photos it appears the stream has maintained it historic pattern however it may have been channelized in the past. Channel and floodprone widths are similar to the sites Big Bend reach (Table 1). However the width-depth ratios are somewhat lower and as a result sediment transport is greater. Point bars are well formed on the inside of each meander though most are 1 – 4 feet above bankfull stage (Figures 8 & 9). Active cutbanks are common along the outside of meanders and there is moderate disturbance on the outer edges of the point bars.

The high point bars are dominated by *Baccharis emoryi*. Some *Salix exigua* is present along the outer faces of these point bars. No cottonwood sprouts or young trees were observed within the reach. Mature cottonwoods and other trees are limited to the upper terraces. A topographic survey was completed on the Grotto and Meander reaches and two representative cross-sections were created.

FIGURE 8. Surveyed cross-section #1 in Birch Creek reach

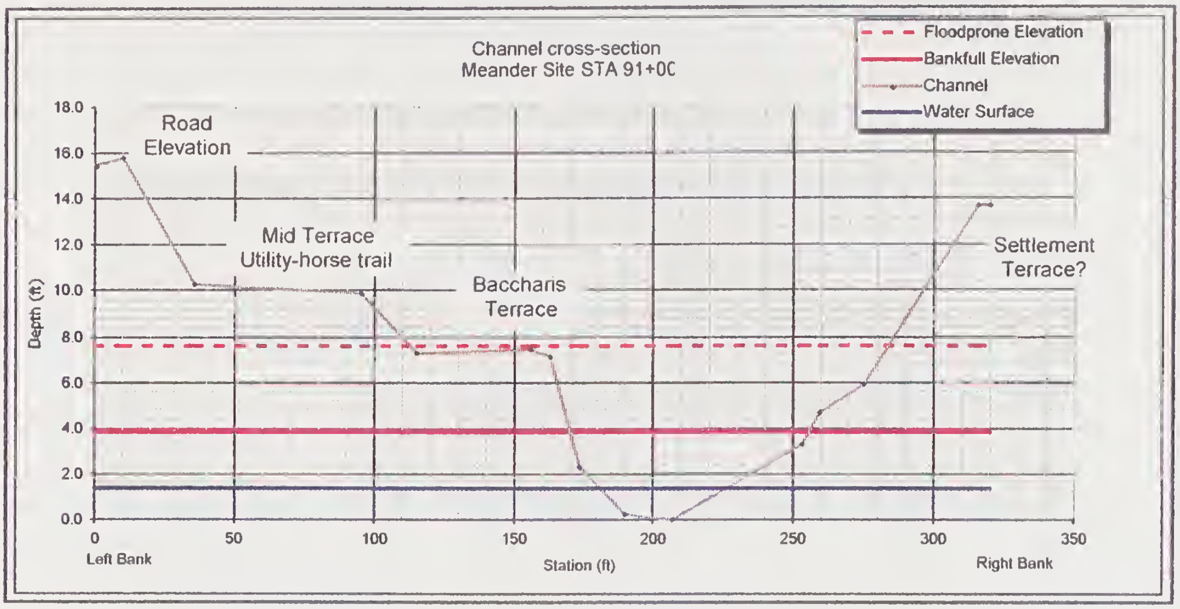
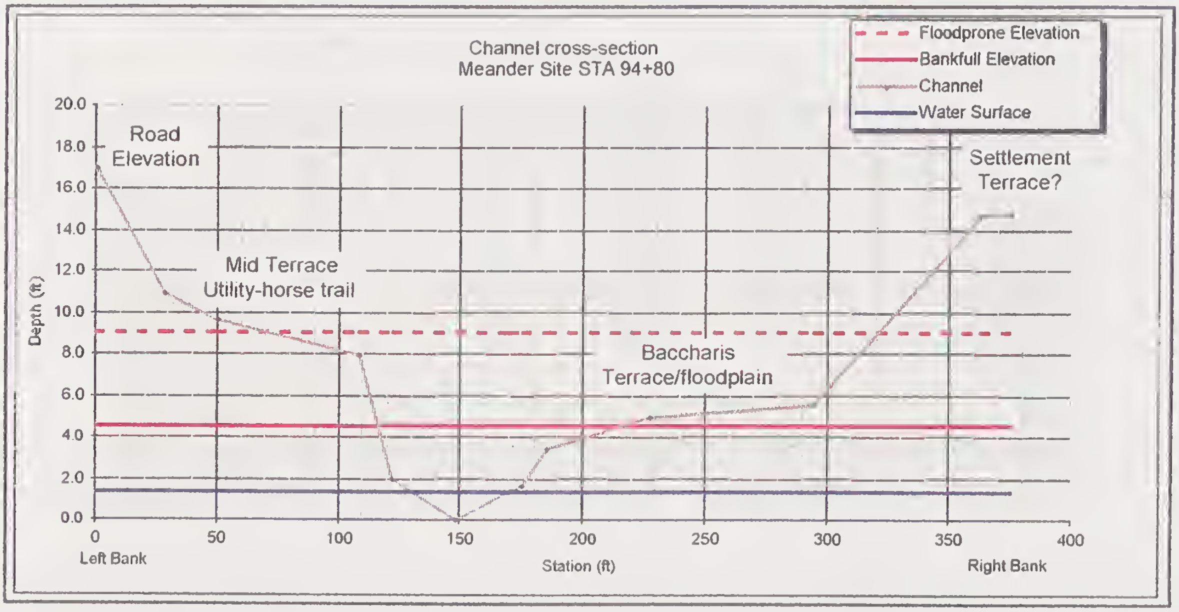


FIGURE 9. Surveyed cross-section #2 in Birch Creek reach



<u>SENTINEL SLIDE AREA:</u>

Major and minor regular slope failures along the Sentinel Slide showed cottonwood invasion, including young age classes occurring along the margins of the toe of slumped lands. In virtually all locations, cottonwood survival was not apparent along the high scour stream within bankfull stage. However, survival appears to be occurring several feet above bankfull stage where disturbance is created by the slumps. These zones of germination are comprised of a mix

of fine silts, sands, and rock fragments and appear to receive moisture from upslope locations rather than requiring a direct connection to the stream hydraulics. This reach was included to illustrate that conditions exist for successful cottonwood recruitment away from the fluvial environment. No cross-sections were surveyed in this reach.

Table 1. Summary of channel and floodplain dimensions for survey sites

NAME	WS Area (mi2)	XS Area (ft2)	Width (ft)	Mean Depth (ft)	Max Depth (ft)	Floodprone Width (ft)	Channel Type
Narrows Site	290	181.9	75.0	2.4	2.9	112.0	B4c
Hereford Site	291	198.4	70.0	2.8	3.4	100.0	B4c
Big Bend Site	291	189.4	120.0	1.6	2.75	245.0	C4
Great White Throne Site	300	198.5	100.0	2.0	4.4	240.0	C4
Grotto bridge Site	320	229.6	72.0	3.2	4.1	105.0	B4c
Meander Site STA 91+00	320	210.9	90.0	2.3	4.5	250.0	C4
Meander Site STA 94+80	320	203.4	85.0	2.4	3.8	140.0	B4c
East Fork Virgin River	340	130.5	42.0	3.1	4.2	260	C5

Table 2. Summary of dimension, pattern, and profile data for survey sites.

NAME	Width/depth Ratio	Entrenchment Ratio	Slope (ft/ft)	Sinuosity	D50 (mm)	Median Material	Channel Type
Narrows Site	30.9	1.5	0.007	1.3	18	Coarse Gravel	B4c
Hereford Site	24.7	1.4	0.005	1.2	34	Coarse Gravel	B4c
Big Bend Site	76.0	2.0	0.009	1.2	40	Coarse Gravel	C4
Great White Throne Site	50.4	2.4	0.007	1.3	30	Coarse Gravel	C4
Grotto Site	22.6	1.5	0.006	1.0	38	Coarse Gravel	B4c
Meander Site STA91+00	38.4	2.8	0.004	1.3	-	Coarse Gravel	C4
Meander Site STA94+80	35.5	1.6	0.004	1.3	-	Coarse Gravel	B4c
East Fork Virgin River	13.5	6.2	0.002	1.3	-	Sand	C5

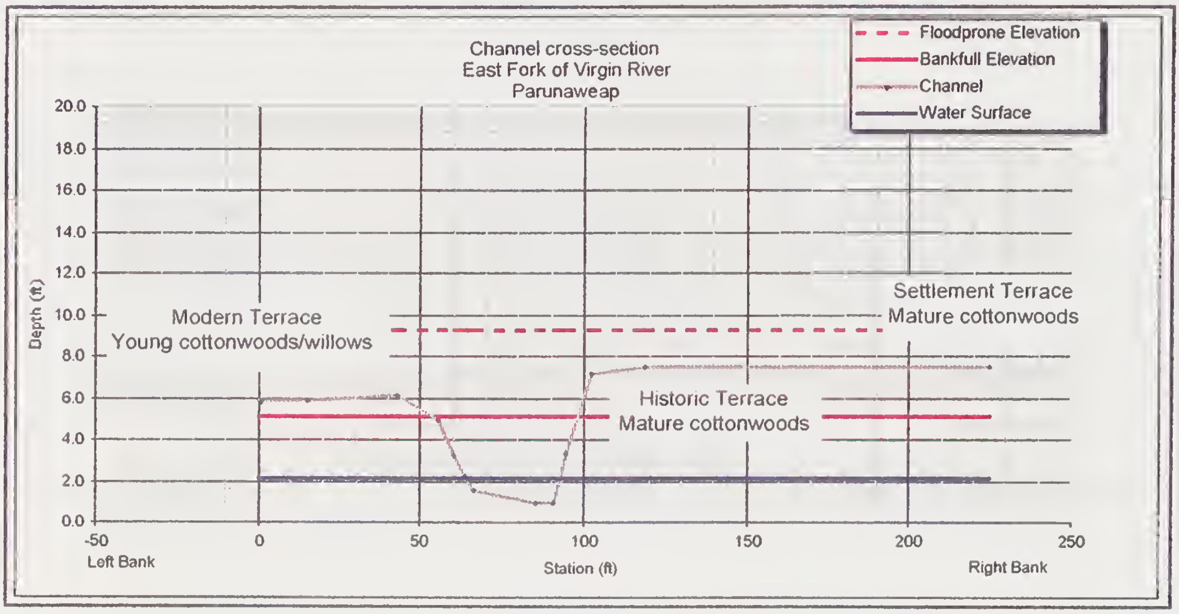
ZION CANYON AND EAST FORK (PARUNAWEAP CANYON) COTTONWOOD CONDITIONS

The East Fork is an northeast-southwest trending tributary to the Virgin River and joins the North Fork in the town of Springdale, UT, just outside the Park boundary. The watershed area is approximately 340 sq. miles, a value similar to that of the North Fork. A single cross-section was surveyed on the East Fork at a site located a short distance above the Park boundary approximately 1.6 miles above Shunesburg townsite. The survey is located within the site described by Hereford (1995) and the cross-section intercepts 3 historic terraces. The stream is a low gradient, single thread, meandering channel with a riffle/run morphology and broad adjacent floodplains. Despite similar watershed areas to the North Fork, bankfull channel dimensions are considerably smaller. The channel is much less incised and a wide accessible floodplain produces a very high entrenchment ratio. It appears that much less channel incision has taken place in the East Fork than the North Fork. Channel, floodplain, and terrace features are

dominated by a sand substrate and it appears that some of the older cottonwood and mesquite trees have been substantially buried over time. It is evident that considerably more sand is supplied to the East Fork than the North Fork.

As in the North Fork, spare bunch grasses and very old cottonwood trees dominate high terraces. Mesquite occupies the terrace margins on south facing slopes. The Modern Terrace lies only slightly above floodplain elevation and contains a rich community of Arroyo or coyote willow (*Salix exigua)* and young Fremont cottonwood (*Populus fremontii)*.

FIGURE 10. Cross-section at East Fork survey site



As a part of this review, we also investigated cottonwood and related environmental conditions along the East Fork of the Virgin River in Parunaweap Canyon. Table 3 summarizes and highlights conditions we observed in each canyon.

Based on these observations, cottonwood has more recently regenerated in the East Fork than the North as indicated by the presence of young isochrone growths in a variety of age classes. The East Fork also has very conspicuous recent depositional and scour areas capable of and that do support cottonwood regeneration. This is occurring in both gap phase opportunities and continuous strand areas within the riverine environment. Shrub-form willow is a dominant shrub in the East Fork and *Baccharis* is absent to sparse; this shrub dominates in the North Fork. The presence of mesquite and some other plant species within the East fork suggests either a plant localized environmental conditions, a difference in history that may have eliminated species such as mesquite within the North Fork Canyon, or that the distribution is related to historic gradients, such as fire gradients. Mesquite is very cold sensitive and grows at the upper elevations of its range in the East Fork area. The wide, east-west trending East Fork receives sunlight even in

winter. The north-south oriented North Fork provides a considerably cooler environment. The cooler temperatures and/or fire gradients may explain the presence and abundance of ash and boxelder within Zion Canyon and their absence or low abundance along East Fork. These observations are consistent with earlier studies (Steen, 1999, Taylor, 1989).

Table 3. Cottonwood regeneration comparison between the North Fork in Zion Canyon and East Fork (Parunaweap) Virgin River, in Zion National Park.

	Cottonwood Regeneration	**North fork in Park**	**East Fork**
1.	Ages classes of isochrones	15-20 years	X <20 years
	Age classes	70-90 years old	40-60 years
		100+ years	90-100 years
2.	Dominance by *Chrysanthamnus*		X
3.	Dominance by *Baccharis*	X	
4.	Presence of mesquite		X
5.	Depositional vs. eroding	Primarily Erosional	Primarily Depositional
6.	Willow invasion	Rare and scattered	Widespread
7.	Possible fire history differences, fire gradient differences	Closed, tight canyon; cool, moist; lightening ineffective.human caused likely	Wide; open aspect; warm-dry; lightening effective with higher fire probability
8.	Human history	Early occupancy	Early occupancy
9.	Gap phase opportunities	Heavy brush covered and native cool season grass cover throughout canyon; little exposed substrates	Sporadic rabbit brush, much exposed substrates
10.	Substrate character in floodplain	Sands, cobbles	Sands, fine sands and silts

Prehistoric human occupancy appears to differ between the East and North Forks, with abundant habitation in the former, and much less in the latter. This is particularly true of the upper parts of the canyon, such as around Zion Lodge. However, experts caution that the lack of evidence may be due to deep burial or washing away of sites rather than complete absence of use. Regarding the long-term presence of cottonwood in the area, there is good evidence of cottonwood in archeological sites in Parunuweap Canyon. No similar archeological evidence has been found on the North Fork, but this may be related to the lack of sites rather than the lack of cottonwood. In the historic period, there was substantial human use in both canyons (Dave Sharrow, personal communication).

COMPETING VEGETATION

Cottonwood is a species that invades and establishes in locations with low competition by other vegetation. It generally only successfully invades into semi-open to completely open high light environments with temporally adequate moisture on fine substrates. It seldom and only sporadically invades into dense shrub, dense herbaceous vegetation, or in or beneath woody vegetation.

Based on these life history strategies and observations in Zion Park, the following points are provided.

A). In general, the historic prime habitats for potential cottonwood invasion are now occupied by other larger cottonwoods and other woody vegetation. This vegetation along with other factors prevents cottonwoods invasion and growth.

B). Areas that would appear to be prime habitat are now dominated by Baccharis (*Baccharis emoryi)* that appear to maintain an aggressive root and canopy presence over depositional areas, including strand areas, within the riverine systems. Baccharis appears to resprout up through fresh deposition as well as promptly reinvade into deeply scoured areas through seedling recruitment. In addition, based on observations, the first year seedlings of Baccharis appear to easily grow larger than cottonwood seedlings, and they also appear to be evergreen, thus showing continued growth before and after cottonwood's growing season. It appears that Baccharis not only invades into fines, but also readily expands into coarser sediments, including in the interstices between cobbles.

C). Non-native, cool-season grasses.
It is our understanding from reading Steen (1999) and other documentation that bunch grasses historically occupied the upland terraces within the park. Now, bunch grasses are rare and a prevailing assemblage of non-native, cool-season grasses cover the ground in all but the driest sandiest depositional areas on higher terraces. This cool-season grass reduces soil-seed contact for cottonwood establishment over a large area of Zion Canyon. Principal species appear to be bromes (*Bromus tectorum, Bromus spp.*), which are winter annuals (e.g., germinate in fall and cover the ground during the winter, spring, and early summer, when they flower and seed) and which effectively reduce cottonwood's seedbed and it's soil-seed contact and thus it's germination potential.

It apparently would require a higher flood event or lower flood events that are strategically timed to reduce this cool-season grass component. The shallow rooted nature of these grasses makes them vulnerable to scour and deposition. However, the prolific seed production and high viability also allows them to easily and promptly reinvade areas where scour or sand deposition has reduced or removed them.

D). Boxelder and velvet ash regeneration.
Conspicuous and apparent regeneration of both of these trees species is occurring substantially more successfully than cottonwood. Both species were observed to invade into all terrace

locations including the higher driest terraces. The species appear in some locations to have isochronal patterns reflecting strand depositional developments, and in other locations are scattered in and amongst *Baccharis*, growing in the understory of cottonwoods, invading into seep and wetland areas, and invading into maintained uplands landscapes around the Zion Park Lodge. Seeds of both have blown up into cliff areas, hanging gardens, and have become generally well distributed throughout the park. Even gambles oak zones on talus above the highest stream terraces are occupied by both species.

Some interesting notes, taken during the field observations and which may be useful to help understand likely woody vegetation changes that appear to be occurring in the park, are as follows:

<u>Ash and boxelder seed rain period:</u>
These species appear to have a prolonged seed dispersal period. They hold and partially release seeds into the fall and winter, and perhaps into spring of the year following the growing season of seed set. This makes seed available for dispersal over a longer time period and would increase the probability of both reaching more locations and being exposed to greater range of conditions. This strategy for seed retention and partial release would be expected to increase the success of these species. In contrast, cottonwood has a relatively short time period of seed dispersal, and the release is usually a single event with no retention or partial release.

<u>Large endosperms and cotyledons:</u>
Both ash and boxelder have large carbohydrate reserves, which provide for greater germination success, and allow for seedlings to establish in less desirable (more competitive) environments, where a species with less reserve would be suppressed before successful establishment occurred. These strategies both favor germination and establishment within a greater range of environmental settings. In contrast cottonwood has very small seeds and disproportionately small metabolic reserves. It does not compete with other vegetation, nor does it invade into dense vegetation cover.

<u>Establishment is not tied to stream dynamic:</u>
Ash and boxelder species were found invading high dry terraces, gambles oak clones, lawns around the Zion Lodge, hanging from cracks in rock overhangs and seeps, and many other locations. The plasticity in their establishment contrasts with cottonwood, which establishes only in moist, competition-less sites, which are mostly along the stream course in suitably moist substrates.

<u>Boxelder and ash are vigorous resprouters and cottonwood is not:</u>
In a stream environment, scour damage that leaves even only a partial root system intact for box elder and ash will likely stimulate resprouting and additional root development. Top damage stimulates vigorous resprouting by these species. Cottonwood on the other hand is less resilient to top damage and scour damage. Cottonwood is also more sensitive to browse damage and may not survive repeated browse events while ash and boxelder appear very capable of survival and continued growth under heavy browsing.

Beaver and cottonwood:
In Zion Park, it appears that beaver preferentially harvest cottonwood over ash and boxelder. What few cottonwoods in recent times have survived to a sapling stage appear very vulnerable to beaver herbivory. Little to no evidence of beaver herbivory on either ash or boxelder was apparent during field observations in the park.

E). Notable absence of *Salix* in the park.
In contrast to many other stream courses in the region, few coyote or black willows are found along the North Fork in Zion Canyon. We do not understand the reasons, as conditions would seem to be conducive for their growth here. What was apparent during the site reconnaissance, was that a few coyote willows are invading along the bankfull stage, but are not spreading beyond this zone. In all cases where willow was observed, *Baccharis* was found dominating the adjacent terraces, and no seeding or rhizomateous spreading willows were found in *Baccharis* stands. We believe *Baccharis* aggressively holds the point bars and strands against willow invasion and establishment. We also observed differential beaver and deer herbivory on the few willows and little to none on *Baccharis.*

EXPLAINING THE CHANGING WOODY VEGETATION CONDITIONS IN ZION NATIONAL PARK

Cottonwood has been documented to be primarily regenerated after floods that reduce competitive vegetation or in newly deposited fine and moist substrate settings. The literature over North America on cottonwood regeneration (*Populus deltoids, P. fremontii*, and perhaps *P. angustifolium*) suggests that synchronized regeneration occurs and cohort recruitment occurs often in spatial patterns reflecting zones of deposition (strands) and that the cohorts are very even aged (isochrones). There is no reason to believe that these patterns and life history strategies would not presently nor historically have occurred in Zion National Park. Notwithstanding, with reference to the above complicating factors that we find very unusual (e.g., *Baccharis* dominance), the presence and future of cottonwood establishment may not occur primarily because of woody vegetation competition. If healthy regeneration of cottonwood was occurring, herbivory would not be significant, nor would it likely represent a measurable threat to cottonwoods. However, with limited invadable habitats for cottonwood in recent years, the few successful cottonwood saplings are a target for herbivory, and a significant and measurable impact on cohort recruitment appears to occur in the park.

Given this information, observations, and trends, the following preliminary explanations and testable hypotheses are offered for consideration and discussions.

In the past, cottonwood recruitment in the park seems to have occurred in three ways as follows:

1. **Event triggered synchronized cohort recruitment** that has lead to isochrones, made up of even-aged stands.

These would occur in areas triggered by flood depositional strands and scour areas where cottonwood seed dispersal, seedling establishment, and saplings temporally and spatially escape (by growth to a less vulnerable larger (taller) size, or by spatial separation from the active channel locations with deposition and scour) subsequent flood events, or where survival of many of the trees occurs even in the face of subsequent high flood events. This process was probably most common and widespread during periods with high flow and sediment conditions and dominated during the establishment of the Settlement, Early Modern, and Modern terraces. During stable periods cottonwood seedlings and saplings establish in secondary channels and margins of slow water velocities and strand development occurs thus offering protection to the developing plants.

We also saw event triggered synchronized growth and recruitment in the toe of slumped slopes, such as described above. The seemingly largely even-aged cohorts of cottonwood growing along the side slopes of the Sentinel Slide opposite the entrance road to the park may be explained in this way.

The abandonment of old agricultural fields also may have been responsible for the establishment of many cottonwoods. Based on observations, it appeared that historic irrigation ditching and field edges are where the larger cottonwoods grow in the park. It also appears that relatively even aged individuals are now growing dispersed across the areas that we believe were historic farm fields.

A series of sub-hypotheses are also provided that could be tested to better understand historic regeneration of cottonwood in Zion Canyon. These are as follows:

- Cottonwood is regenerated after big scour events on strands within 1-2 feet vertically of the bankfull stage.
- Cottonwood regeneration occurs after big flood events on higher terraces only during above average regional moisture or with appropriately timed follow-up storms that maintain seed/soil moisture and contact.
- Cessation from farming may also be able to explain apparent even-aged stands on larger upper terraces that may have been historic farm fields.
- Slumps at the mouth of the canyon created valley plugs that every 30-100 years have surcharged Virgin River waters over the valley bottom, including the higher terraces, which could have resulted in suppression and mortality of competing vegetation and reinvasion opportunities for cottonwood.

2. **Opportunistic and minor flood event** invasion that leads to scattered individual tree recruitment and sporadic numbers of recruited trees.

It appears that scattered individual cottonwood trees are present in higher terraces and other locations within the fluvial environment. Scattered trees rather than development of isochrones can be explained by the random presence of successful seedling and sapling recruitment. This gap phase invasion would only occur in locations with appropriate patch size, substrates, and moisture conditions. We observed this to occur in locations on dredge or deposited spoils along old drainage ditches, in seepage locations at the toe of the cliff faces, and perhaps in locations on strand lines, where gaps in *Baccharis* were present.

3. **Planting and landscaping introduction** may account for a large number of trees in areas that simply cannot be explained by stream fluvial processes.

Obviously, plantings can occur most anywhere, and it's likely, although we cannot support this with planting records, that they did occur in locations where stream revetments were installed, in locations in association with the lodge and other facilities in the park. Records of landscape architecture plantings in the park would be worth gathering, if available, and reviewing to better understand the woody vegetation systems in the park.

Of particular interest would be the determination if such plants as *Baccharis* were extensively utilized in the park as a part of the planting programs of yesteryear. Although native to the region, the density and extent of the Baccharis communities to the exclusion of willow seem out of balance. Our preliminary review of the behavior of this plant in the park, suggests strongly that it may in fact been extensively used by the CCC in streamside plantings.

In addition, advertent and inadvertent plantings of non-native, cool-season grasses (*Bromus spp*., etc.), that were identified to have been conducted during the 1930's (Steen 1999), have also had unforeseen ecological effects on the recruitment of native species, including trees such as cottonwood. Some of these grasses establish very quickly on scoured areas and, in essence, reduce the window for gap phase or isochrone invasion to occur, because of the dense vegetation cover they create quickly. These grasses could have colonized extensively on fallowed fields providing a rich seed source during stream channelization activities.

In the uplands terraces around the Zion Lodge there appears to be older trees mixed with mid-aged trees in a pastoral landscape setting. It is very confusing and difficult to explain the presence and establishment of these trees in any other way, but having been planted as a part of a cultivated landscape.

Recent colonization theory.

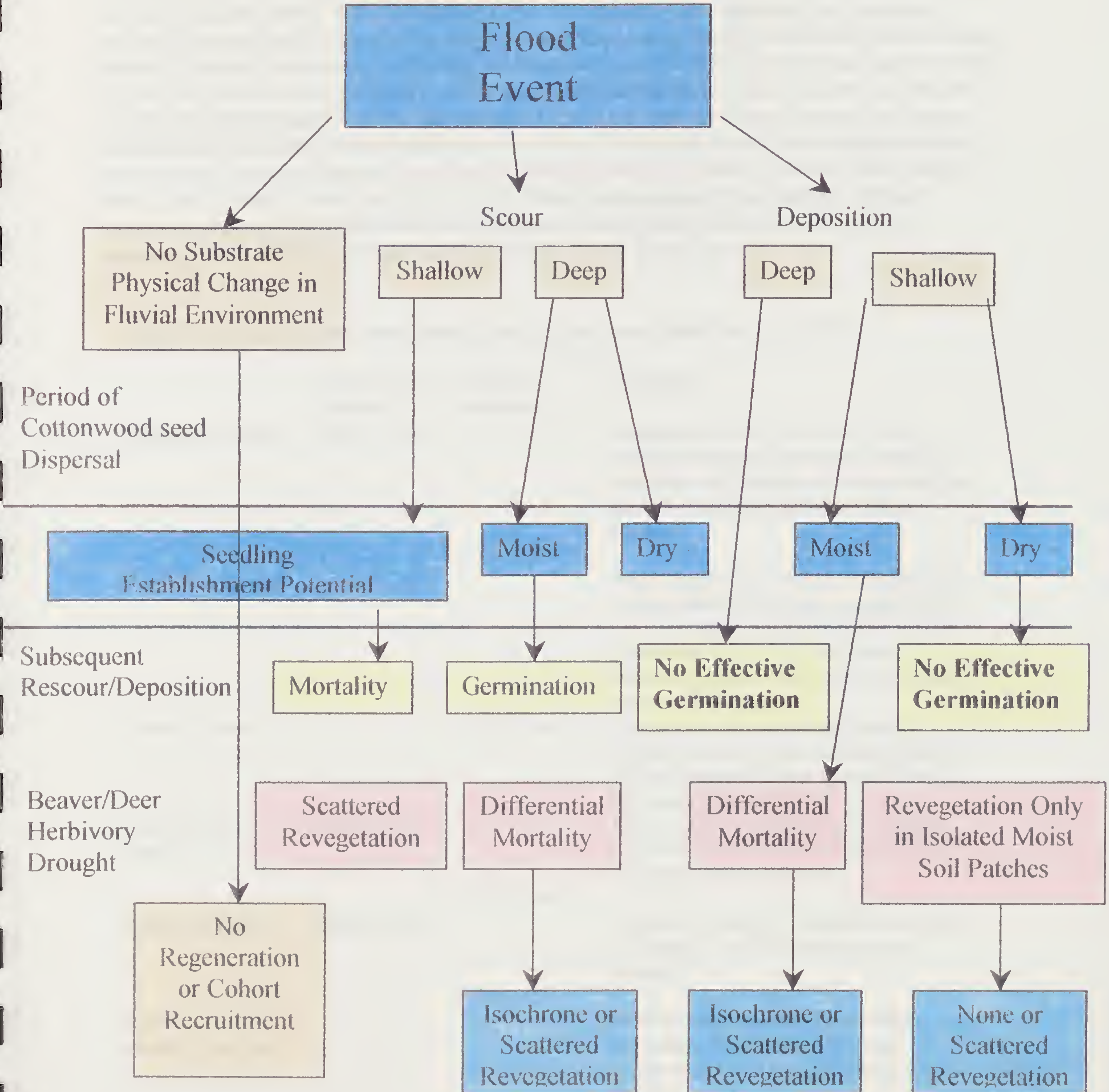
There may be some evidence both in the literatures and on the land, that cottonwood and large trees in general may not have been a substantial element of the historic Zion Canyon system, and that colonization may be a human-induced and post-settlement change. This theory does not negate nor support the models above, in fact, colonization could have occurred, and stand regeneration still can occur by the methods above.

Observations within the canyon suggested little to no buried historic logs within the terraces and fluvial deposits within the park. This is very unusual not to find buried logs that were covered by historic flood events and terraces. We reconnoitered along the entire canyon and simply did not find evidence of historic woody debris.

The absence of all but recent dead trees (which is located on the surface of the terraces) may also be explained in part, if the following factors prevailed in the park in historic times.

- Wood use during presettlement and post settlement times utilized all the woody debris found within the canyon, including the excavation of larger buried and perhaps partially exposed historic trees/logs. There is evidence of post settlement land clearing, and wood utilization, but no mention of exhuming buried logs. Also, it would be unlikely that all larger logs would be exhumed, there should be ample evidence of historic larger trees.
- Perhaps increased wood-use, and fires, which are typically associated (and have been documented elsewhere to occur) with human occupancy before and after Indo-European settlement, simply restricted woody vegetation system establishment within the park until after initial post-settlement Indo-Europeans departed the canyon.
- Perhaps, buried woody debris is not present because it simply decomposed. This would include buried historic and recent surficial debris.
- Because Fremont's cottonwood is at the upper end of its elevation range within the park, it may simply be that this species has truly only recently invaded. It could also be that it (perhaps along with velvet ash and boxelder) was introduced into the park for wood production and shade and perhaps other amenities it may offer.
- This can also be explained if the hydrology at the turn of the century that produced terrace features also temporarily provided the necessary conditions for widespread cottonwood recruitment. As the hydrology shifted from depositional to erosional the terraces were abandoned and cottonwood forest preserved. Since cottonwoods and terraces would be of similar ages, few if any older remnants would be buried.
- Finally, some of the absence of buried logs could be attributed to especially zealous "landscaping" by the CCC during the channelization period.

FIGURE 11. Preliminary outline of the relationships between flood events, scour, deposition, moisture substrate conditions, and cottonwood germination and recruitment



CHANNEL GEOMORPHOLOGY

Cottonwood trees along the Virgin River within Zion Canyon are intertwined with the stream's fluvial processes. Seeds depend on stream flows for dispersal and adequate soil moisture. In addition, the ultimate survival of seedlings is dependent on protection from subsequent scouring events. The story of stream morphology has been well described by Hereford and others (1995). Periods of erosion and deposition over the past 500 years have alternately created and eroded a variety of alluvial features within the canyon (Table 4). A number of cottonwood trees were cored during this study to date depositional terraces. Tree ring and other data suggests that the majority of mature cottonwoods are linked to terrace features created in three distinct periods; 1867 – 1883, 1892 – 1906, and 1926 - 1937. Other studies suggest that regional climatic variation combined with watershed management created periods of alluvial deposition alternating with periods of stream cutting (Hereford and Webb, 1992).

Table 4. Terrace features along North Fork Virgin River (Hereford, et al, 1995)

	Depositional Periods	Channel Deepening	Description
Prehistoric Terrace	~800 - ~1100		Fine-grained sands with a very thin coating of calcium carbonate. Probably correlates with prehistoric terraces in East Fork. 3-4 m (10-13 ft)* above active channel.
		1100 - 1200	
Settlement Terrace	> 1200 - 1883		Vegetation is a woodland of Gambel oak with subordinate boxelder. Agricultural use is probable. 3 m (10 ft)* above active channel and 1-2 m (3-7 ft)* above Historic Terrace. Oldest cottonwood trees found on this feature.
Historic Terrace		1883 - 1926	This terrace was the stream channel beginning in the 1890's and abandoned by 1926. Cottonwood trees present. 2 m (7 ft)* above active channel.
Early Modern Terrace	1926 - 1937		This terrace was originally a floodplain formed below the historic terrace. 2 m (7 ft*) above active channel.
		1937 - 1940	
Modern Terrace	1940 - 1980		Primarily created by record flood of 1966 (9,150 cfs). 1 m (3 ft) above active channel*.
		1980 - 1983	
Active channel/floodplain			Includes active stream channel and floodplain. Floodplain elevation is approximately 0.5 (1.5 ft)* above active channel.

*All elevations measured at Hereford Site.

The age of the existing cottonwood forest within Zion Canyon appears to date to these periods suggesting that cottonwood recruitment has been historically timed with above average regional moisture periods, which contribute higher sediment yields as well as higher flood events. Natural channels are created and maintained by the forces of water and sediment from their watersheds. Stream channels like the Virgin River may be as sensitive to changes in sediment loading as they are to flood magnitude, frequency, and duration. Increasing sediment supply forces the channel to adjust creating wide and shallow channels. As the channel widens, bank erosion contributes additional sediment, compounding the problem. The wide shallow channel morphology results in a relatively high ground water table and extensive overbank flows during even minor flood events. Historic photographs show a broad, braided channel during at the turn of the century. These conditions would exacerbate flooding of adjacent farmland and destroy in-stream structures and accounts of the period describe extensive flooding and destruction of farmland. homes, and diversion structures. But these conditions would be excellent for widespread and successful cottonwood reproduction.

GEOMORPHIC CONDITIONS FOR SUCCESSFUL RECRUITMENT

Successful cottonwood recruitment requires four conditions.

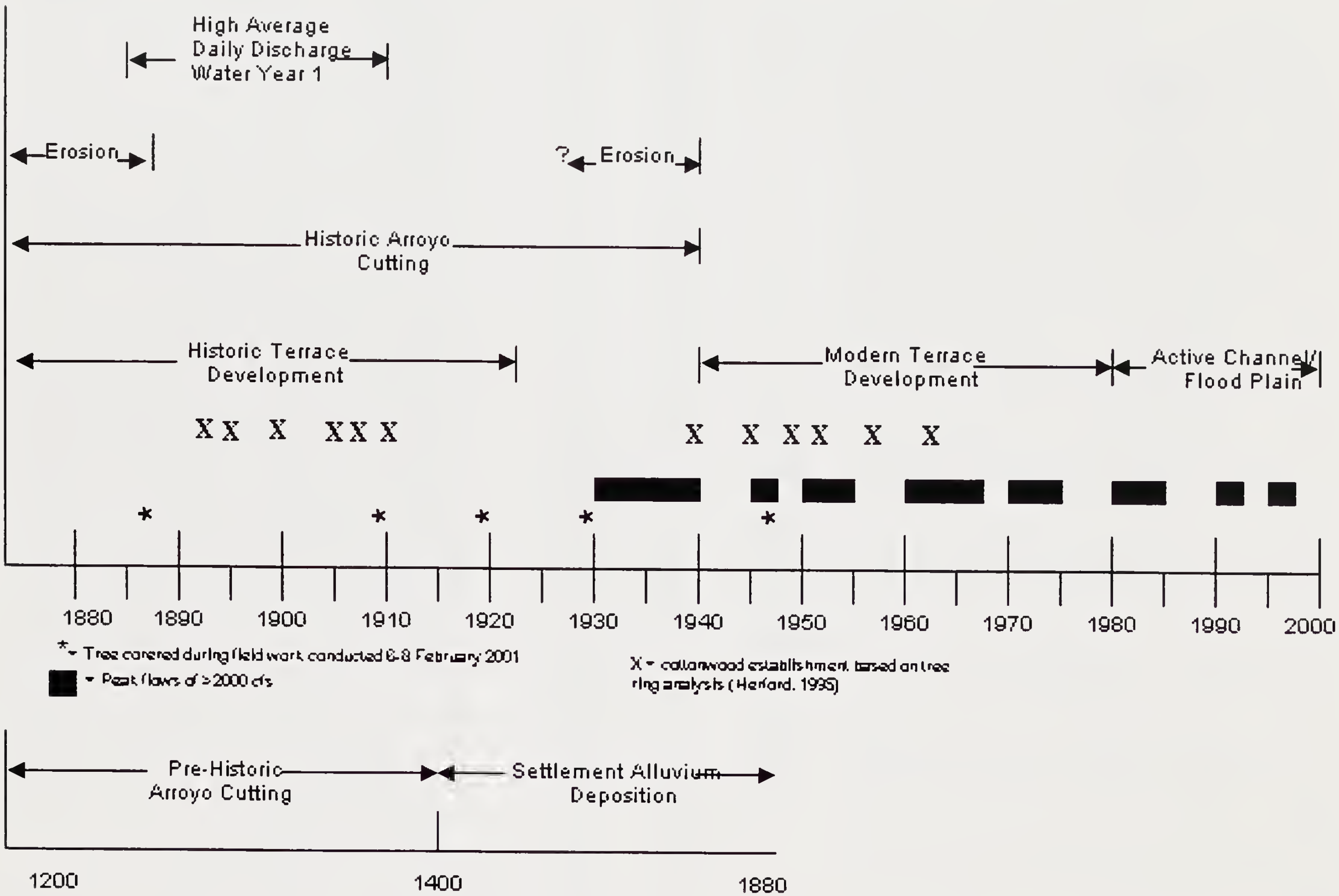
- Stream flows adequate to distribute wet substrate above base flow;
- Fine-grained, bare substrate for germination;
- Adequate ground water though the summer season to establish a root system; and
- Enough distance from stream channel to protect seedling from subsequent scour.

During historic depositional periods high sediment loads created bare ground from overbank deposition. Channels were wide and shallow with low, easily accessed floodplains and overbank flooding was extensive. Shallow channels and relatively high summer flows maintained high ground water tables. Subsequent erosional periods deepened channels protecting vegetated features as elevated terraces removed from stream erosion.

The current climate and channel morphology limits the extent of flooding. The North Fork of the Virgin River has remained relatively stable vertically since the incision events ending in 1983. As a result of incision, the channel is bounded by higher terrace features that limit overbank flow. Geologic control in the Narrows reach and constructed revetments in the Zion Lodge and Birch Creek reaches create narrow, deep channels (width-depth ratios from 25 – 35) and severely limit floodplain width (entrenchment ratios from 1.4 – 1.5).

Narrow channels and floodplains produce high sediment transport conditions limiting erosion and deposition in these reaches. The resulting stable bank vegetation (baccharis and cool season grasses) severely limits available bare ground. In the wider, unconstrained reaches (Big Bend) a shallow, meandering channel (width-depth ratios of 50 to 75) and wider floodplain (entrenchment ratios of 2.0 to 4.0) creates larger areas for potential recruitment. However these same conditions provide limited protection from subsequent scour. While average spring flows have remained relatively constant, summer flows have declined sharply since the turn of the century (Hereford, et al, 1995) lowering ground water levels. See Tables 1 and 2 for a comparison of channel and floodplain dimensions.

Figure 12. Preliminary Correlation of Storm Discharge, Fluvial Feature development and Erosion, and Cottonwood Tree Establishment Based on Records Provided by Herford et al (1995) and Herford and Webb (1992).



Assumptions:
1. Tree age accuracy.

Data Gap:
1. Need more tree age data
2. Affect of revetments on stream flow and concurrent cottonwood establishment and recurrent.

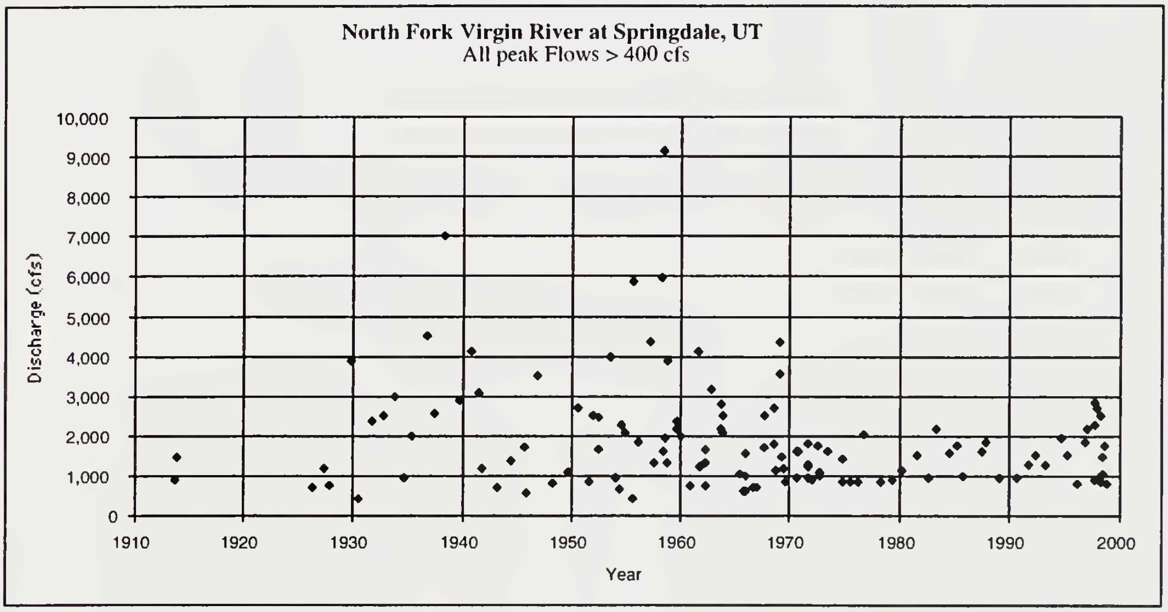
Hypotheses:
1. Tree establishment correlates with terrace development and high flow events, followed by moderate to low flow events, i.e. generation is dependent on deposition disturbance, survivorship/ advanced growth depends on subsequent moderate to low flows, and recruitment / dominance is dependent on terrace abandonment.

HYDROLOGY:

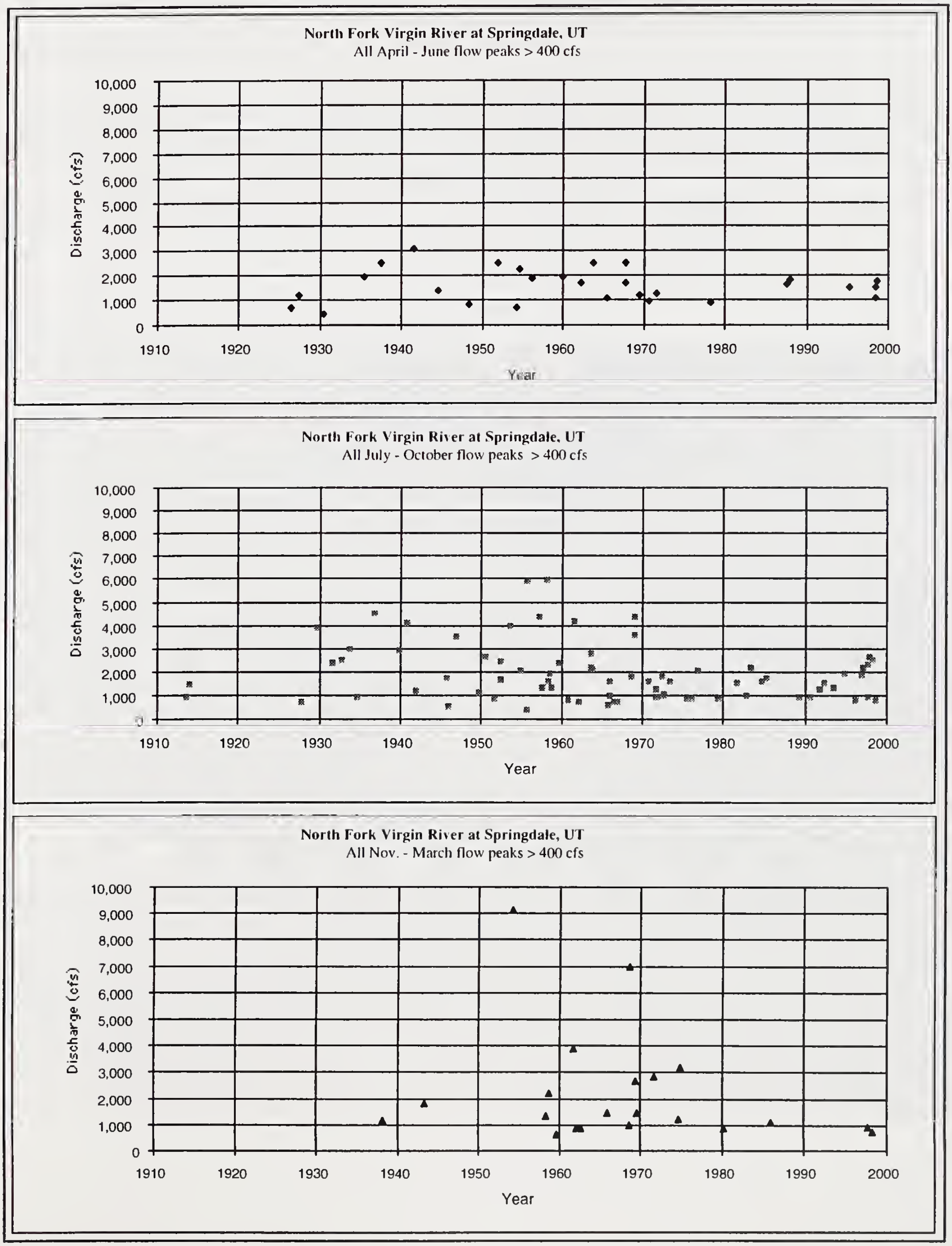
Cottonwood recruitment requires adequate stream flow to wet seeds on adjacent fine-grained floodplain deposits and sufficient soil moisture through the dry summer season to sustain the sprouts. Spring flood flows (which have the longest duration) occur during cottonwood seed dispersal and are responsible for wetting substrate for germination. Figure 13 shows the period of high flow events between 1940 and 1970. Since 1970 high flows have been relatively small. As discussed in Hereford, et al (1995), regional hydrology has changed dynamically in the past 150 years. All flow peaks greater than 400 cfs recorded at the USGS gaging station at Springdale, UT are graphed on Figures 14 a, b, & c. It appears that spring flood flows were more frequent during the Modern terrace (1940 – 1980) period and somewhat higher than those of the past 30 years (Figure 14a). A similar trend is apparent for summer and fall (Figures 14 b & c). The significance of the relatively few winter peak flows from 1926 through 1958 is not clear. Higher and more frequent spring flow events would have allowed more widespread seed germination. Hereford (1995) reports that average daily summer flows decreased sharply during the past 75 years. This would lower the ground water table during the critical summer months and reduce survival of sprouts.

The conclusion of this analysis is that current hydrology limits but does not eliminate the potential for cottonwood regeneration in Zion Canyon.

FIGURE 13. All peak flows greater than 400 cfs at North Fork Virgin River at Springdale, UT gage. (1913-14, 1926-98)



FIGURES 14 a, b, c. Peak flow events greater than 400 cfs by season. North Fork Virgin River at Springdale, UT gage station. (1913-14, 1926-98)



CONDITION OF EXISTING REVETMENTS

The location, volume of material, and condition of the revetments in the reaches below the Grotto footbridge were documented for this project. In general, the revetments are constructed of relatively small rock rip –rap (6 – 16 inches) and covered with heavy wire. The gabions line the east bank almost continuously from above the Grotto footbridge to well below the Zion Lodge. The revetments are from 6 – 12 feet in height and 4 – 8 feet thick. They contain an estimated 90,000 square feet of wire and 8,500 cubic yards of rock.

Much of the revetment is in surprisingly good condition considering it was constructed 60 – 70 years ago. However in many places the wire has rusted away and become a safety hazard. In the area near Emerald Pools the river has breached the revetments on both sides of the river and created a sharp meander. In other places the wire has given way and the rock is dropping out the bottom of the basket and into the river. For a more details see Appendix 3.

FIGURE 15. Rock revetments in disrepair near Zion Lodge

DESIGN CHANNEL/FLOODPLAIN GEOMETRY

In general, proper channel and floodplain geometries can be best determined by identifying a functioning reference reach within the project or nearby watershed. However, preliminary assessment of the East Fork and main Virgin River below Zion Park suggested that these channels would not provide suitable reference conditions for the North Fork. As a consequence reference conditions for the physical channel were quantified from data taken at the Big Bend and Great White Throne sites in Zion Canyon. In these reaches young cottonwoods and other woody species were observed in depressions and secondary channels in floodplain areas adjacent and only slightly elevated above the stream channel. While this recruitment may appear limited compared to the extent of the cottonwood forest that now occupies the valley floor, it probably represents the potential under current climate.

Design Criteria

Component	Average	Range
Drainage Area	~200 sq miles	NA
Bankfull Cross-sectional Area	200 sq feet	175 – 225 sq feet
Width-depth ratio	50	40 – 75
Entrenchment ratio	2.5	2.0 – 3.0
Sinuosity	1.3	1.2 – 1.4
Design channel floodplain dimensions		
Bankfull Channel width	100 feet	85 – 125 feet
Bankfull mean depth	2.0 feet	1.6 - 2.4 feet
Bankfull maximum depth (1.6 d_{mean})	3.2 feet	2.5 – 3.8 feet
Floodprone width	250 feet	200 - 300
Meander width		
Meander length		
Radius of curvature		

FIGURE 16. Design cross-section overlaid on existing cross-section near Zion Lodge reach

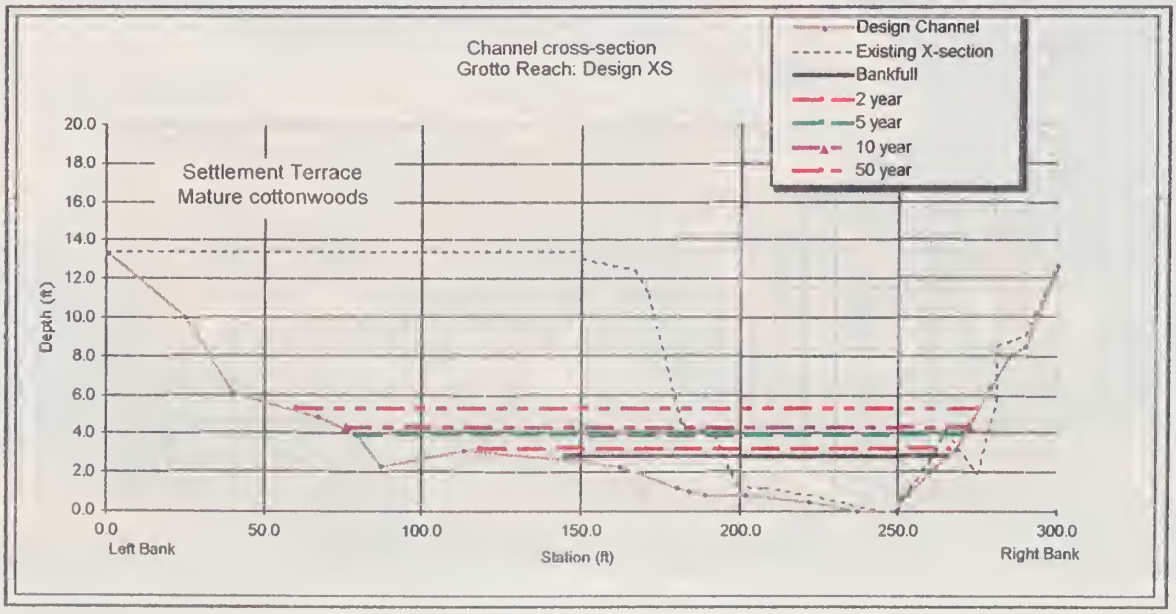


FIGURE 17. Design cross-section overlaid on existing cross-section near Birch Creek reach

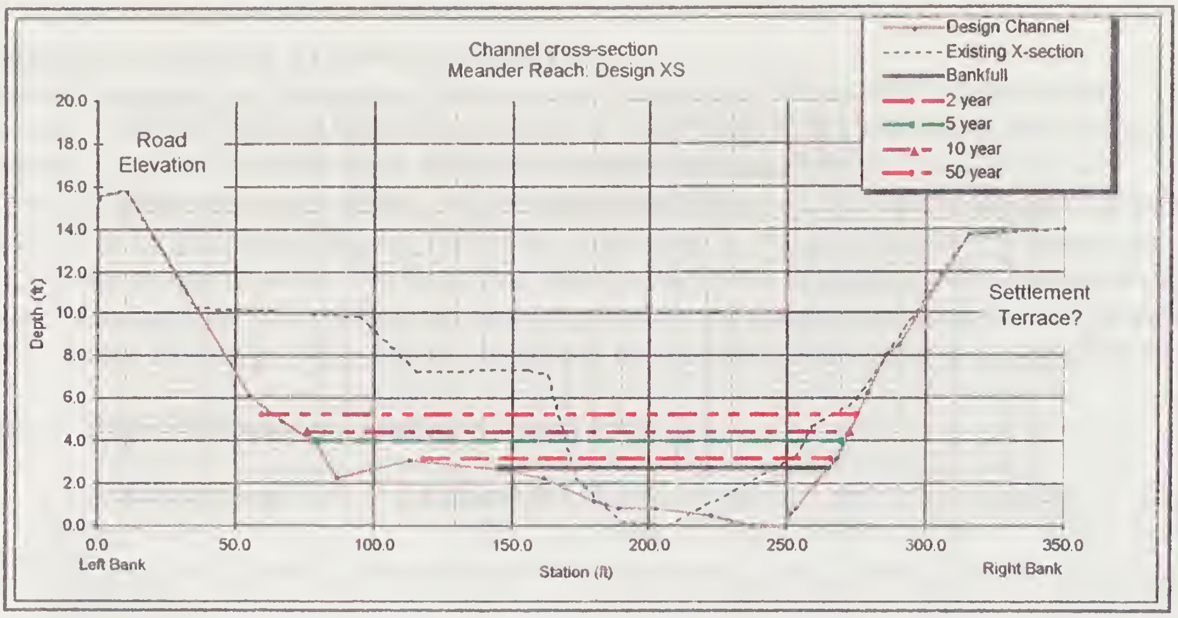


FIGURE 18. Photo of Big Bend reach

ASSESSING DESIGN FLOOD POTENTIAL:

Flooding potential was evaluated at the surveyed sites using WinXS-Pro, a cross-section analyzer developed by the USDA Forest Service. Flood magnitudes and return intervals were modeled using HEC-FFA, a flood frequency analyzer developed by the Army Corps of Engineers. While the stages should only be considered estimates, the values suggest that there is not likely to be additional flooding risk in the lodge area as a result of increasing floodplain width in the reveted reaches. Big Bend Site which exhibits the floodplain width closest to the design cross-section. These stages are superimposed on the design cross-sections in Figures 14 and 15. Stage Discharge relationships are plotted on surveyed cross-sections in Appendix 1.

Table 5. Stage-Discharge relationship at survey sites.

Return Interval (years)	1.3 (Bankfull)	2	5	10	25	50	100
Discharge (cfs)	1,150	1,600	3,000	4,000	4,500	7,500	9,000
SITE							
NARROWS	3.0	3.3	4.4	4.5	4.9	5.6	5.9
HEREFORD	3.4	4.0	4.8	5.3	6.2	6.4	6.8
BIG BEND	2.8	3.2	3.9	4.3	4.4	5.3	5.7
GREAT THRONE XS-1	4.2	4.7	5.5	5.9	6.1	7.0	7.4
GREAT THRONE XS-2	3.4	4.3	5.1	5.5	5.7	6.5	6.9
GROTTO	3.9	4.6	5.6	5.9	6.2	7.7	8.2
MEANDER STA 9+00	3.8	4.1	5.1	5.5	5.7	6.3	6.6
MEANDER STA 9+80	4.2	4.5	5.6	5.9	6	6.5	6.7

Table 6. Stage-Discharge relationship for design cross-sections

Flow	Discharge	Stage
Bankfull discharge	1150 cfs	~ 2.8 feet
2 year	1600 cfs	~ 3.2 feet
5 year	3000 cfs	~ 3.9 feet
10 year	4000 cfs	~ 4.3 feet
25 year	4500 cfs	~ 4.4 feet
50 year	7500 cfs	~ 5.3 feet
100 year	9000 cfs	~ 5.7 feet

DESIGN SUMMARY

From the analysis of current geomorphic and biological conditions in the Big Bend reach suggests that increased floodplain width is the single most important element to restore the potential for cottonwood recruitment in the reveted section of the North Fork of the Virgin River within Zion Canyon. However due to the channel's deep entrenchment, this will entail the removal of a large volume of material. A set of potential alternatives is evaluated in the next section. In the final discussions a series of options are presented for further discussion.

EVALUATION OF MANAGEMENT ALTERNATIVES

The following alternatives were evaluated based on the design criteria.

1) Remove Levees and Construct Channel with Natural Characteristics - The levees would be removed and a channel would be physically constructed for the entire 1.5-mile reach, with dimensions and patterns similar to natural conditions and consistent with a channel in equilibrium

Discussion: This alternative would potentially provide the channel morphology to optimize cottonwood regeneration and other riparian function. Removal of the rock and wire would increase visitor access to the stream corridor and lower public safety concerns. Design of the channel meander pattern should decrease the risk of unpredictable channel adjustments and unforeseen infrastructure impacts. This alternative would allow all construction to be completed within a single funding cycle. However, economic costs and initial physical disturbance would be greatest under this alternative. There are a number of critical data gaps that could result in a less successful outcome. A number of mature cottonwood trees would almost certainly have to be removed.

Basic tasks:

5) Remove ~ 90,000 sq. feet of wire mesh and dispose of properly
6) Remove ~ 8,500 cu yds of rock revetment. Some could be used to in creating the channel meanders and/or in channel fill. The remainder must be transported off site.
7) Excavate ~ 500,000 cubic yds of terrace material. Approximately 255,000 cu yds of material would have to be transported away from the site.
8) Install bioengineering and replant disturbance areas.

Estimated costs:

- Remove wire: $50,000
- Remove rock: $100,000
- Earthwork: $1,500,000
- Bioengineering and stabilization: $100,000

TOTAL ESTIMATED COST: $1,750,000

2). Remove Levees - The levee material and rock filling the gabions would be removed and deposited in the channel to raise the streambed or disposed of elsewhere.

Discussion: Complete removal of the levies would allow the stream to adjust it pattern and channel/floodplain geometry. Transportation of the rock would be moderately expensive unless a use could be found for it in and around the Park (parking lots, planters, road dividers, etc). There is no location within the stream with a predominance of sized or shaped rock similar to the revetment rock. Actively placing rock in the stream channel or passively allowing it to fall into the channel may swamp the kinetics of the stream resulting local channel scouring and/or increased and unpredictable bank erosion.

Most of the revetment rock is from 6 to 12 inches (150 – 300 mm) in diameter which is equal to the D85 or greater for the channel bed (Table 7) D85 refers to the percentage of that size class present in the stream, in this case 85% of the particles are this size or smaller. Some of the revetment rock may be incorporated in the channel bed but any large and uncontrolled supply of this size rock may result in unpredictable and undesirable channel adjustment. These adjustments may result in morphologic conditions that would aid cottonwood and other riparian species but the resource and infrastructure impacts are hard to assess and predict.

Basic tasks:

9) Remove ~ 90,000 sq. feet of wire mesh and dispose of properly
10) Remove ~ 8,500 cu yds of rock revetment. Some could be used to in creating the channel meanders and/or in channel fill. The remainder must be transported off site.
11) Excavate and remove ~ 255,000 cubic yds of terrace material from site. Approximately 255,000 cu yds of material would have to be transported off the site.
12) Install bioengineering and replant disturbance areas.

Estimated costs:

- Remove wire: $50,000
- Remove rock: $100,000
- Earthwork: $750,000
- Bioengineering and stabilization: $100,000

TOTAL ESTIMATED COST: $1,000,000

Table 7. Channel bed particle size distribution for surveyed sites

	D15 (mm)	D50 (mm)	D85 (mm)	D100 (mm)
Narrows Site	sand	40	110	218
Hereford Site	16	60	140	310
Big Bend Site	2	60	120	309
White Throne Site	8	45	100	362
Grotto Site	20	55	110	256

3). Breach Levees and Construct Selected Meanders - Wire would be entirely removed, the levees physically breached in a few places and 2-4 meanders constructed outside of the levees to hasten lateral movement of the channel.

Analysis: This alternative would presumably nudge the stream channel toward a more stable meander pattern and result in floodplain areas that would encourage cottonwood regeneration. Costs would be moderate since only selected rock would be removed.

However, the analysis within this report suggests that floodplain elevation and width are more critical than simply restoring meander pattern. Since the current revetments are generally only 100 feet apart, the creation a floodprone width of 150 – 250 feet would

require the removal of virtually all revetments. Leaving large quantities of loose rock riprap would increase the potential for undesirable channel adjustments. This alternative would likely increase the potential for only slightly. This alternative does not appear to meet project objectives.

Basic tasks:
13) Remove ~ 90,000 sq. feet of wire mesh and dispose of properly
14) Remove ~ 8,500 cu yds of rock revetment and transport off site.
15) Bioengineer and replant disturbed areas.

Estimated costs:

- Remove wire and : $50,000
- Remove rock: $100,000
- Bioengineering and stabilization: $100,000

TOTAL ESTIMATED COST: $250,000

4) **Remove Wire Only** - The wire would be removed from the gabions to hasten the river's actions and reduce hazards.

Analysis: Removing the wire only will hasten natural deterioration of the revetment structures and remove the public hazard created by the rusting wire baskets. Because the rock riprap is not sized to withstand high stream flow velocities, flow events will likely undermine the structures and allow the rock to enter the bankfull channel. It is not clear the effect this additional cobble will have on the system. We are concerned about overwhelming the stream by simply allowing revetment rock to fall into the stream.

There is no location within the stream with a predominance of sized or shaped rock similar to the revetment rock and there is concern that it would result chaotic and unpredictable stream channel adjustments (Table 7). Large pulses of rock into the stream channel would likely redirect the stream and interrupt the forming meanders.

Bank erosion, and subsequent sediment supply downstream, will increase as the stream channel forms a more meandering pattern. The exact location of channel meanders would likely conflict with existing vegetation (mature cottonwoods) and/or existing park infrastructure (trails, footbridges, etc.). Bank erosion that undermines mature cottonwoods would increase risks to visitor safety.

In our estimation, this alternative would likely result in surcharged water levels and accentuated hydraulics during even lower flood flows. While bank erosion and increased sediment supplies may improve the sediment dynamics of the reach, there is no certainty that conditions conducive to cottonwood recruitment would be created.

Basic tasks:

16) Remove ~ 90,000 sq. feet of wire mesh and dispose of properly
17) Remove ~ 8,500 cu yds of rock revetment and transport off site.
18) Bioengineer and replant disturbed areas.

Estimated costs:

- Remove wire and : $50,000
- Remove rock: $100,000
- Bioengineering and stabilization: $100,000

TOTAL ESTIMATED COST: $250,000

5) **Benign Neglect** - Allow the gabions to deteriorate and the river to slowly remove the levees.

Analysis: Many revetments are failing and rock is currently falling out of the bottom of the revetments. This is creating differential armoring which will produce unpredictable stream morphological changes. The stone fall would temporality armor one side of the stream bank, which will send unpredictable and destabilizing oscillations and hydraulic pulses and erosive forces down the stream. This alternative would also result in no opportunities for cottonwood regeneration. While no additional construction or maintenance costs will be incurred, we expect continued failure of the revetments and the exacerbation of the stream morphological changes and problems. Deteriorating wire and rock will lessen natural aesthetics of stream and pose increasing public safety risk. This alternative would not meet project objectives and is not recommended.

Costs not estimated

6) **Retain Levees** - The levees would be maintained for the foreseeable future. This would require repair and some replacement of gabions.

This alternative would require no increase in the current maintenance costs to the Park. However this management would not achieve any of the objectives for natural function or cottonwood/riparian improvement.

Costs not estimated

SUMMARY &CONCLUSIONS

- Observations and some additional tree coring made during the project confirmed the conclusions of earlier research that the woody species composition is shifting within Zion Canyon. Fremont cottonwood (Populus fremontii), once the dominant woody species, has limited recruitment and is now co-dominant along with Box elder (*Acer negundo*) and Velvet Ash (*Fraxinus velutina*).

- The mature cottonwood forest that currently exists throughout Zion Canyon is the result of unique climate, land-use, and hydrologic conditions that occurred during the turn of the century and again, to a lesser degree, in the 1940 – 1960's. These conditions resulted in high sediment loads that aggraded the stream channel and caused widespread bank erosion. With a sediment laden channel and a low, broad adjacent floodplain, overbank flows were common and produced optimum conditions for widespread cottonwood regeneration across the Canyon floor. Subsequent channel deepening protected the young cottonwood forest from later stream scour.

- These "unstable" conditions led to the channelization of the river and the installation of rock and wire revetments throughout the Canyon. The installation of these structures coincided with climatic conditions that deepened and stabilized the channel. The combination led to further incision, especially in the area of Zion Lodge.

- The East Fork Virgin River maintains a much more stable community of cottonwoods with few gaps in age classes. However, although this watershed is adjacent and has nearly the same drainage area, it does not serve as a reference for the North Fork. Aspect (east-west vs. north-south orientation), greater apparent sediment supply, warmer temperatures, less channel incision, and smaller channel size differ markedly from the North Fork.

- Current cottonwood recruitment is limited and confined to a relatively narrow strand along the banks and floodplains of the North Fork of the Virgin River. Recruitment is most successful along those reaches that have active channel dynamics, that is some lateral movement that produces erosion and deposition. The Big Bend Reach typifies these conditions.

- Cottonwood recruitment and other floodplain processes are severely limited in the Zion Lodge and Birch Creek reaches by the channelized nature of the stream and by a competition from other species, primarily baccharis (Baccharis emoryi). This species and a variety of cool season grass species dominate point bars and other low alluvial features leaving little bare ground for cottonwood recruitment.

- The absence of broad, active floodplains inundated by frequent, moderate flow events appears to be the primary missing component in the lower half of the system. Efficient sediment transport through the reveted sections limits erosional and depositional processes which is essential to provide necessary substrate for cottonwood recruitment.

RECOMMENDATIONS & WORKSHOP TOPICS

Of the alternatives evaluated, three (retain levees, benign neglect, and remove wire only) will not move toward project objectives of restoring floodplain function and cottonwood recruitment. On the contrary, these three management actions may produce additional adjustments to the system. A fourth alternative (breach levees and construct selected meanders) could restore meander pattern but would not be sufficient to widen floodplains and is not recommended. We suggest the workshop discussions focus on the remaining alternatives and a set of common components that can be implemented throughout the system. The remaining management actions should be considered as initial topics for the technical workshop:

A) Remove Levees and Construct Channel with Natural Characteristics

Complete removal of the levees and the construction of a design channel and floodplain would potentially provide the greatest benefit. This alternative would improve the riparian function and provide greater public access for recreation and aesthetics. It would entail significant excavation and removal of channel, floodplain, and terrace material and the loss of a number of mature cottonwood trees.

B) Remove Levees

This alternative would consist of complete removal of both wire and rock. In order to be effective the floodplain needs to be widened. In addition to removing the levees, the channel and floodplain would be widened significantly. In theory, over time the channel would erode laterally and establish a wider meander pattern. Significant excavation would be necessary and a number of mature cottonwood trees would be removed.

C) Raise the level of the concrete grade control structure at Birch Creek

If implemented in combination with channel widening and/or realignment, this action could raise the channel bed level increasing the local water table and reducing excavation needs. Although in-stream structures generally impact natural channel functions and require on-going maintenance, the unique setting at Birch Creek site makes this option worth considering. The existing structure appears to be effective and stable. The structure is sited at a morphologic transition from alluvial valley to narrow canyon created by the Sentinel Slide.

D) Refine the STELLA model as a tool to guide future management

Modeling can provide a useful tool to integrate current understandings and future monitoring data into management decisions. The STELLA modeling initiated during this project could provide that tool.

E) Restore opportunities for cottonwood recruitment as tributary streams cross terraces

In several locations especially in the upper reaches of the Canyon, low profile revetments protect backfilled areas where non-native grasses prevail. There is no cottonwood regeneration occurring in these areas. In these locations the revetment would be removed, the previously filled floodplain be excavated, and the materials removed. In addition, microtopographic features would be created during regrading in this restored floodplain environment. Grading of lower swale bottom areas within the microtopograpic features would be to an elevation 6 inches to 18 inches above the lowest elevation of the bankfull

floodplain. We would then propose that the ditched upslope seepage water that is now directed to the river also be rerouted to these created wetland system.

Additional elements for consideration
Any restoration activities should focus on restoring the biological system as well as the physical. Bioengineering practices which depend on plantings of willow and other woody species should be considered in areas where bank stability is poor or has been disturbed.

F) Reduce non-native, cool-season grass
We recommend that several experimental plots be installed to test various strategies for reduction of non-native, cool-season grasses within the riverine environment. We would recommend that 3-5 plots be installed that extend from the high terrace, across other terraces and to the river's current bank full floodplain. The plots should be no smaller than 50 meters in width by the length required to span the fluvial terraces. Within these areas we propose that one of several methods be tested for reducing the cool-season grass component. Roto-tilling appears to be a possible way to reduce these shallow rooted grasses. Two roto-tillings to a depth of 6-8 inches each should reduce these grasses. Do the first tilling, then a few weeks later the second.

A second method could involve spraying with the grass herbicide Poast or equivalent. Following label instructions, spray the study areas carefully to reduce the cool-season grasses.

We would recommend that the test plots simply be monitored for vegetation change, including invasion by cottonwood and other species. To do this, we would recommend the installation of end-monumented relocatable parallel transects be installed that run the length of the experimental plots. Sampling nested along the transects would include woody vegetation recruitment measurements in 4 meter wide continuous quadrat belts centered over the transects. Herbaceous vegetation would be measured in 1 meter square sample quadrats located every 5 meters along each transect length. A minimum of 3 such transects per experimental plot is recommended.

G) Reduce *Baccharis*
The very unusual dense, persistent, and widespread stands of *Baccharis* represent a major impediment to cottonwood and willow establishment within Zion Canyon. A project could be designed to test the extent of disturbance necessary to allow willow and cottonwood to complete with Baccharis. The project would also provide the opportunity to test phytotoxicity of *Baccharis* on cottonwood and willow seedlings Using the same methods as above, presample the chosen test plot areas. Then using whatever methods (e.g., manual grubbing and removal, or herbicide application (perhaps Garlon 4a), remove *Baccharis* and sample study plots for vegetation response.

As a part of this process, in one test plot it may be advisable to introduce seed of willow and cottonwood simply by collecting seeds from the region (and elsewhere within the canyon) and dispersing the seeds within the test plots. Follow-up monitoring would be to best understand response. We recommend that test plots be maintained for a period of no less than 3 years.

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ATTACHMENT 1. STELLA model performances and assumptions for key variables

MODELING COTTONWOOD REGENERATION

This report section elaborates on a potential model, and begins the development of a STELLA model to test and better understand the opportunity to regenerate cottonwood.

Model Methodology

To predict the changes to the regenerated cottonwood community under changing conditions, a model which can quantify variable values of the factors which affect the tree as a function of time and manipulate these variables to predict resulting tree population fluctuations (also as a function of time) is necessary. This model should provide a design and analysis function for users which can easily incorporate time dependent data from a variety of sources; be easily used and readily available; be stable and robust; and allow the results to be presented in graphical and tabular formats. For these reasons, use of existing software, which provides a suitable environment for the model, was set as an objective of this analysis effort. The *"Stella"* software (Stella Research, 1997) was found to provide a suitable operating environment for the model. *"Stella"* allows model parameters to be easily modified and automatically extrapolates these changes through the entire model; it provides time related graphs and tables of modeled results for any of the model variables; and is robust and stable with good documentation. High Performance Systems, the software manufacturer, allows a free run-time version to be used with the cottonwood model which will allow additional model simulations with variables changed by those interested in further evaluation of cottonwood regeneration.

Prior to development of a model, we began further exploring potential relationships between key variables that may control cottonwood's current opportunity for regeneration and recent performance within Zion Park. Figure 1 attempts to summarize key temporal fluvial events and cottonwood ages on terraces, provided in records and analysis in some previous Virgin River studies (Hereford et al 1995; Hereford and Webb 1992). Even with limited cottonwood age data from the riverine terraces this summary suggests clearly some very revealing trends as follows:

1. It is clear that the Zion Canyon reach of the Virgin River has experienced decisively understood flood events and that these both periods of aggradation and degradation. Some of these terraces (and flood events) have been dated to specific land-use changes including settlement of the region by Native Americans, and later intensive use by Indo-Europeans. Some have also been dated to regional climatic changes that have been well documented.
2. Cottonwood tree regeneration appears to correlate closely with depositional periods of terrace building rather than erosional periods.
3. Terrace development appears to very closely correlate with periods of recurrence of flood events of greater than 2000 cfs, which correlates with bankfull stage events or larger within the canyon, and the periods of terrace development.
4. Erosional periods have occurred during normal stages rather than at or above bank full stages within the river.

A preliminary identification of Key variables
Much interpretation and ideally various types of additional data would be necessary to more fully identify key variables and develop empirical models to both explain cottonwood's performance in the park, and test its regenerative potential. Notwithstanding, we herein begin to develop a potential model framework to integrate the above information. This preliminary framework is then integrated and empiricized in the STELLA model section that follows. A final section in this report identifies additional data needs to actualize this model. This modeling effort is fully adjustable and can integrate any and all variables that can be quantified or even scaled.

Figure 2 provides an outline of key variables and preliminary relationships between these variables. This model suggests that EVENTS trigger no physical changes and either high or low depositional or scour episodes. If these events are timed with a seed release by cottonwood, and if ample persistent moisture is present (either by repeat rain events, seepage from upslope areas, or a river stage and capillary connection), then cottonwood regeneration can occur in bare substrates resulting from deposition or scour. In open substrates that are dry, germination does not occur. If germination occurs on low relief terraces adjacent to the stream, subsequent minor event flood flows will scour cottonwood seedlings and mortality occurs; if germination occurs on low relief areas off secondary channels, greater protection from scour is provided and a greater probability for cottonwood seedling survival occurs. Cohort recruitment only occurs on high relief terraces, if a soil deposit is present that retains moisture (e.g., a fine sediment deposit--silts, clays, or organic matter) or if water is available through additional rain fall or damp, humid, dewey, and warm periods, or if seepage from canyon upslope areas and springs maintains moist substrate conditions after cottonwood seed dispersal occurs. **Note that additional rainfall is unlikely in this the driest portion of the year. Note that seed viability is measured in days rather than weeks.**

For purposes of this modeling exercise we have assumed that competition by *Baccharis* occurs where *Baccharis* has a canopy cover of greater than 50%, though competition can occur at far less canopy coverages, if *Baccharis* is allelopathic. **Larry Stevens can answer this.** At 50% or greater, cottonwood isochrones cannot develop and occupy the space also occupied by *Baccharis*.

We also assume that, at canopy coverages of less than 50% *Baccharis,* only random scattered individual cottonwood invasions occur.

We also assume that ash and boxelder invasion can occur in *Baccharis* at lower *Baccharis* canopy coverages. We have assumed that ash can invade into *Baccharis* stands with a canopy coverage ranging from 15-95%, and that boxelder can invade into *Baccharis* canopies with 25-80%.

We have assumed that, where cool-season non-native grass canopy is greater than 50%, cottonwood cannot invade successfully, while ash and boxelder do effectively invade in 95% canopies.

Suitable substrate and moisture conditions for cottonwood germination obviously are key and controlling variables for cottonwood regeneration. However, survival of seedlings of cottonwood is obviously another key variable. Key variables that affect survival include recurring flood scour or relatively deep deposition of alluvium. For purposes of this model, we have assumed that 80% of all seedlings of cottonwood occupy the bank full stage environment, and that of these, only those in rear channel environments survive, we have assumed that 50% of seedlings establish adjacent to the active channel and 50% in rear protected channel environments. We also assume that 20% of seedlings initially establish in terrace side slopes and other locations offered protection from the active channel processes.

Of these surviving seedlings, we assume that in years 1-5 that the mortality within suitable environments to be 80%, 30%, 20%, 15% and 10% and that at the end of the 5th year mortality is between .5-1% per year in all locations, where germination has occurred. This mortality is contributed to by fluvial processes, drought effects before seedlings roots reach the phreatic surface and have a reliable water supply, from occasional browsing of seedlings by deer and beaver (and other rodents and insects), and some apical bud gall and disease problems that were observed occasionally on seedlings and sapling cottonwoods.

In addition, we assume that by the 5th year, cottonwood saplings are vulnerable to beaver herbivory and that during years with low recruitment that mortality from beaver herbivory ranges from 50-90% of the population. During years with high cottonwood recruitment mortality ranges from 5-10% per year between years 6-25, when cottonwood is assumed to be less vulnerable to beaver felling. This assumes that beaver prefer saplings and younger smaller trees rather than trees of 50-60 ft height and 10-15 inches diameter.

STELLA MODEL

Model Elements

"*STELLA*" software uses four basic elements to structure a model. These are:

- *"Stocks"*
- *"Flows"*
- *"Converters"*
- *"Connectors"*

Stocks are the accumulators of trees or seedlings in the model; *Flows* transfer the trees into and out of the *Stocks*; *Converters* allow *Stocks* or *Flows* to be expressed in different terms, describe variables explicitly which are used to calculate *Flows*, and provide for input of external variables into the model. *Connectors* link *Converters* to *Flows*, *Stocks*, and other *Converters*; *Flows* to *Flows* and *Converters*; and *Stocks* to *Flows* or *Converters*.

Stocks -- In the cottonwood regeneration model, *Stocks* are used to count the tree population and to accumulate trees maturing from seedlings. Additional stocks are used to accumulate deposited or remove scour sediment at the regenerated cottonwood analysis sites.

Flows -- In the model, separate *Flows* are used to remove dead trees from the cottonwood community and to add maturing trees into the community. Flows are also used to transfer sediment in and out of the cottonwood analysis sites.

Converters and Connectors -- Each variable or constant used to describe the tree, sediment or Virgin River flow in the model was identified as a specific *Converter*. The *Converters* were placed into the equations needed to process the model using *Connectors*. Arithmetic values and functions and graphical relationships required to calculate correct values for the equations were added to these equations.

The information above, along with observations provided from within Zion Park and Zion Canyon and Parunaweap Canyon and from region-wide observations, have stimulated the development of a model to begin to explain and test cottonwood regeneration opportunities within the Zion Park. This model is developed using available data, observation and surmised relationships, with which we offer up speculation on relationships between variables that we have used in the development of this preliminary model. Using these various sources of information and future testable hypotheses, we have quantitatively characterized what we believe to be key relationships for the performance of each variable.

FIGURE 4 provides the STELLA model schematic, that relates the key variables identified above. Preliminary data has been input into the model but additional work will be required to allow modeled results to be obtained.

FIGURE 4
STELLA MODEL FLOW CHART

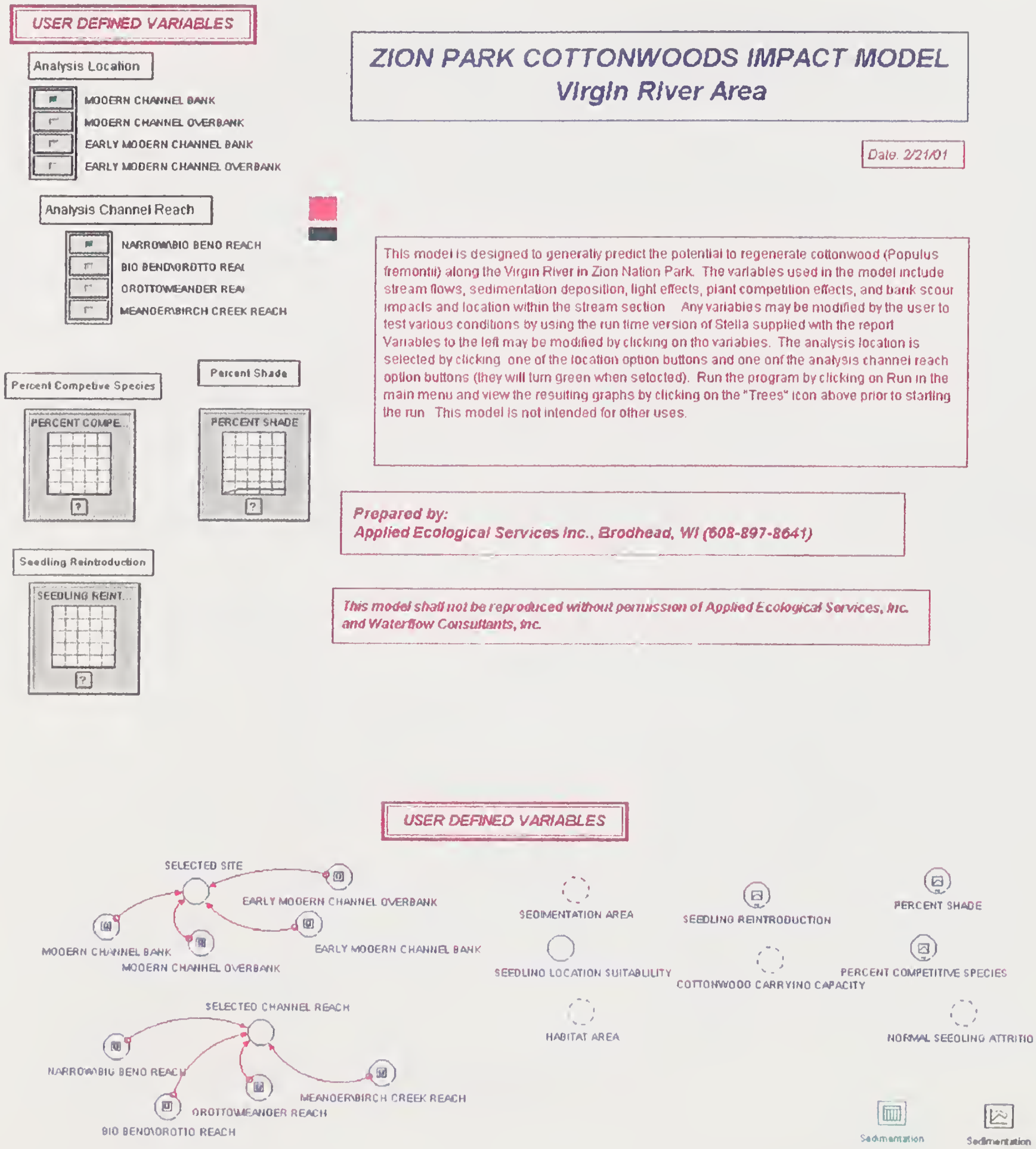
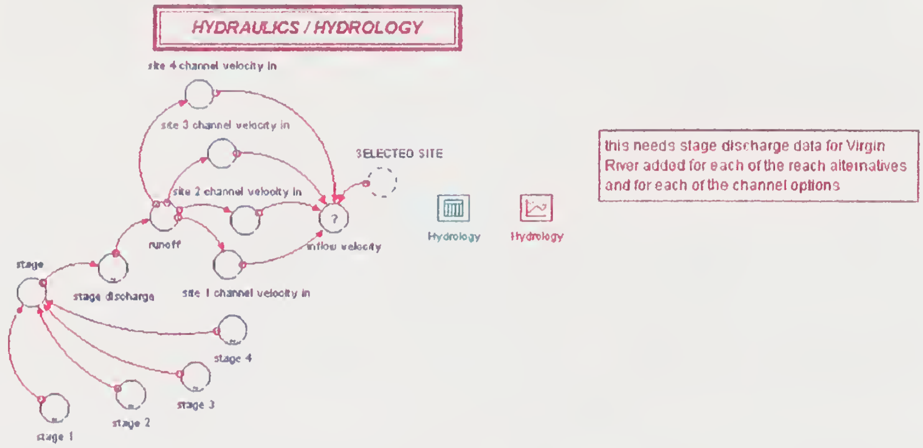
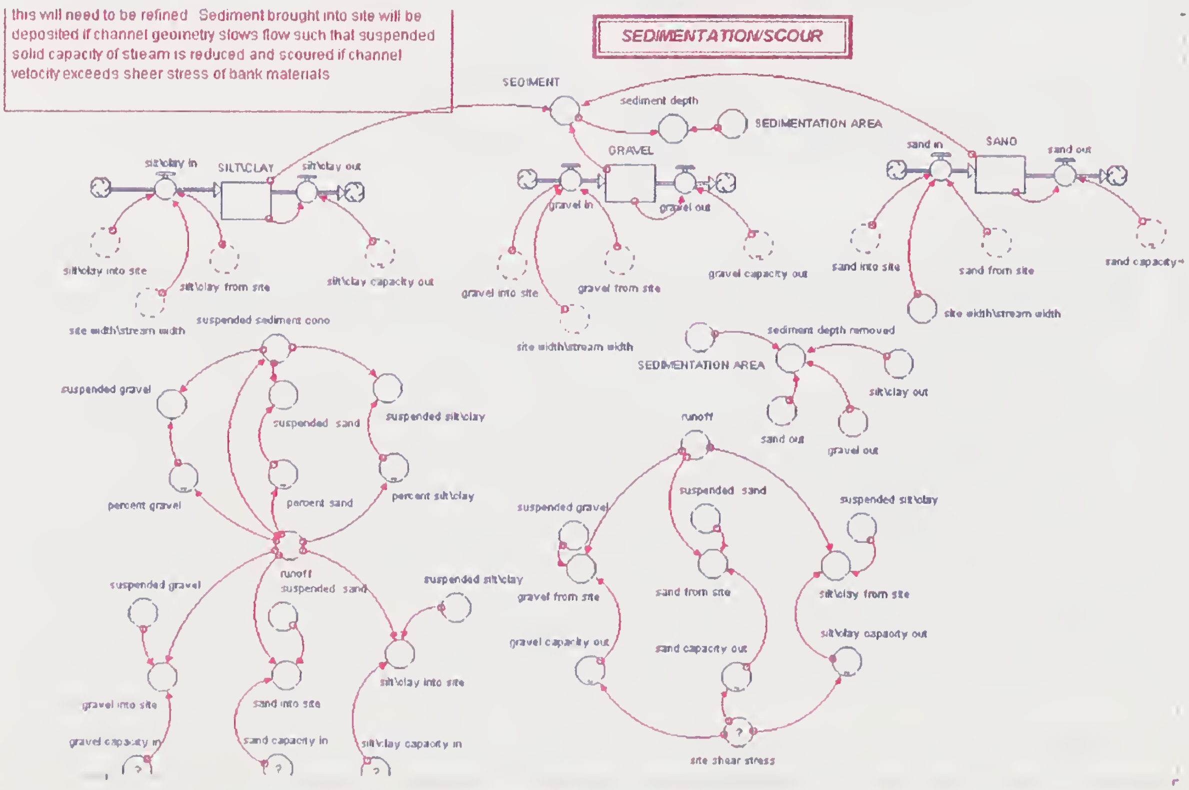


FIGURE 4 (Cont.)
STELLA MODEL FLOW CHART





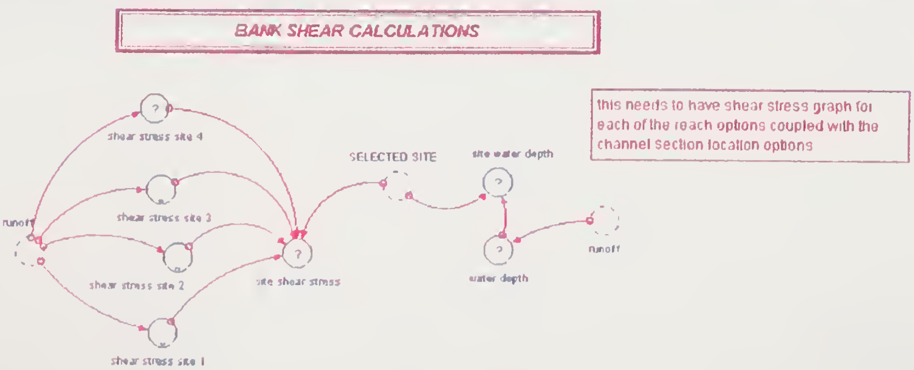
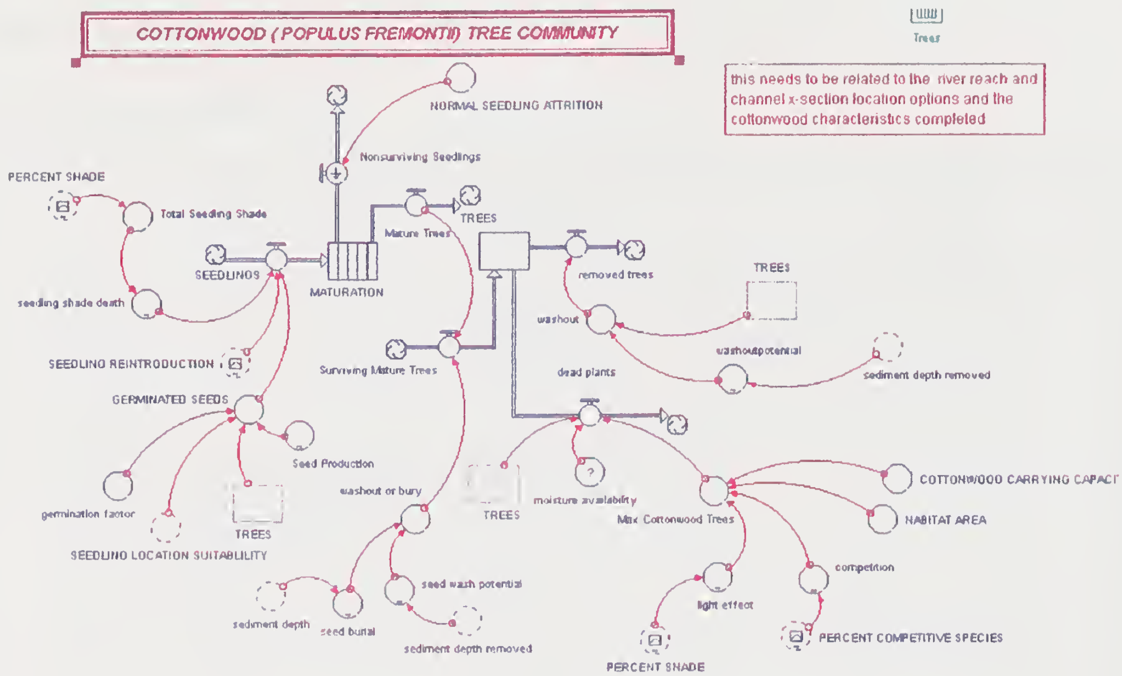


FIGURE 4 (Cont.)
STELLA MODEL FLOW CHART



DATA GAPS

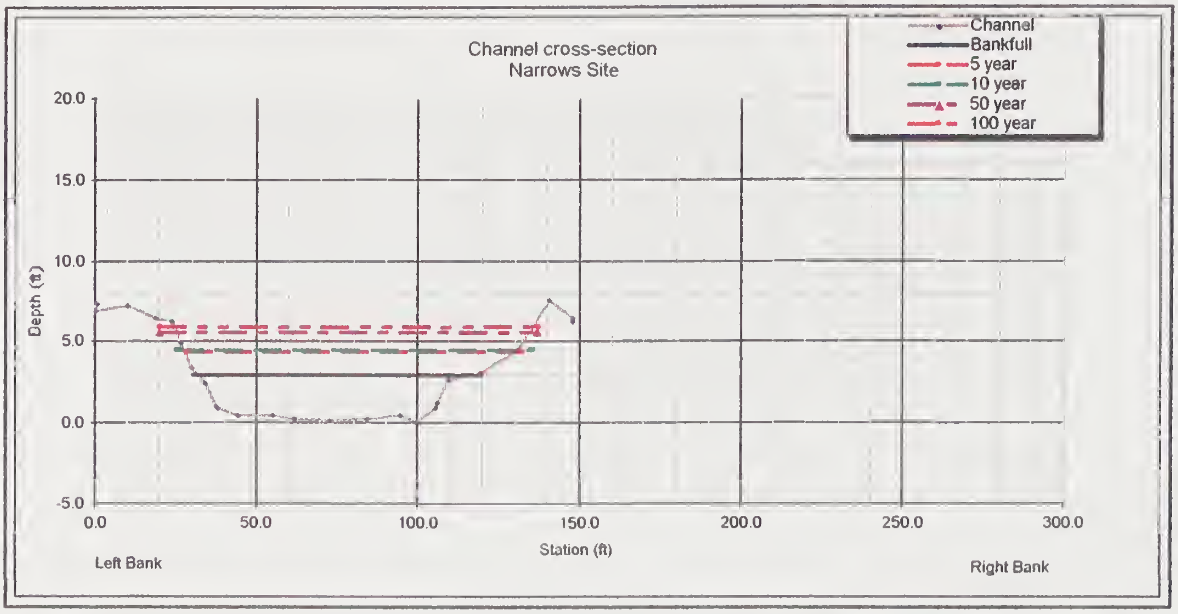
To accuracize the model and more importantly to understand the best ways to go about creating opportunities for regeneration of the ecological, aesthetic and cultural opportunities provided by continued cottonwood regeneration in the Zion Park, some key additional data would be very important to procure. The key day include the following:

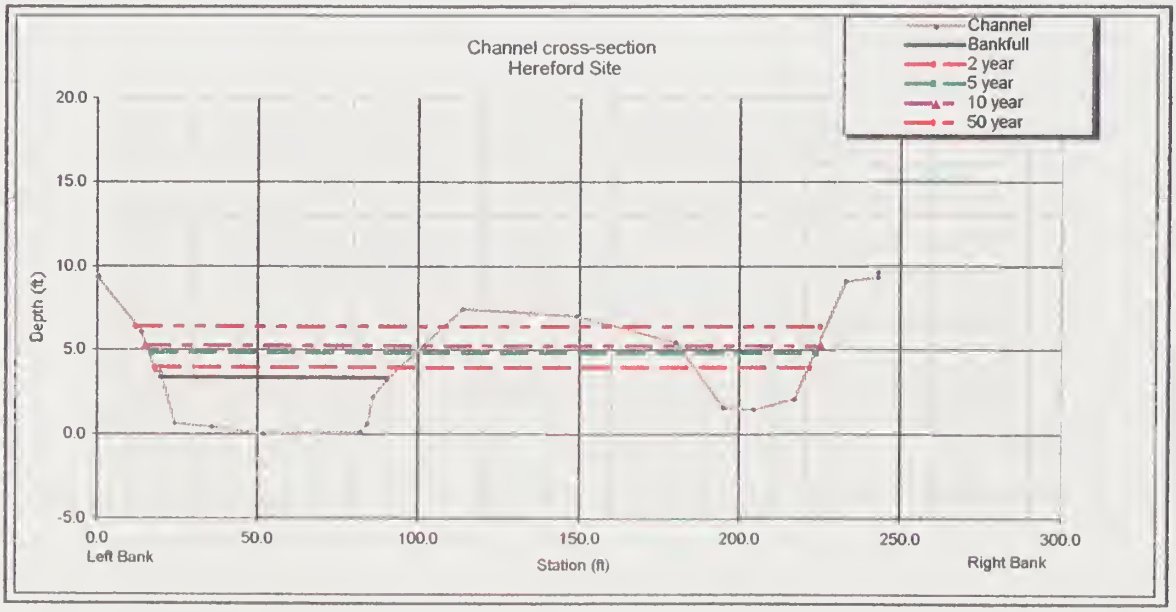
1. A comprehensive tree study to gather additional tree age data and locational information that relates tree age to the specific fluvial geomorphic features within the park.
2. Measurement of cottonwood, ash, and boxelder tree seed rain, dispersal patterns, the timing of the seed rains, and seed viability. **Seed dispersal is widespread.**
3. Measurement of herbivory rates at seedling, sapling, and mature tree life stages.
4. Greater exploration of historic land-uses in the park that may have been responsible for cottonwood generation, including agricultural uses, history of beaver in the Virgin River system, introduction of cool-season non-native grasses, history of *Baccharis* in the canyon, and landscaping that occurred with in the canyon.
5. Longevity of cottonwood seed, does it contribute to seed banks; does it remain viable longer if buried or on the soil surface? **This can be answered**
6. History and distribution of *Salix* in the watershed.

ATTACHMENT 2. Stage –discharge relationships for surveyed cross-sections

NARROWS REACH

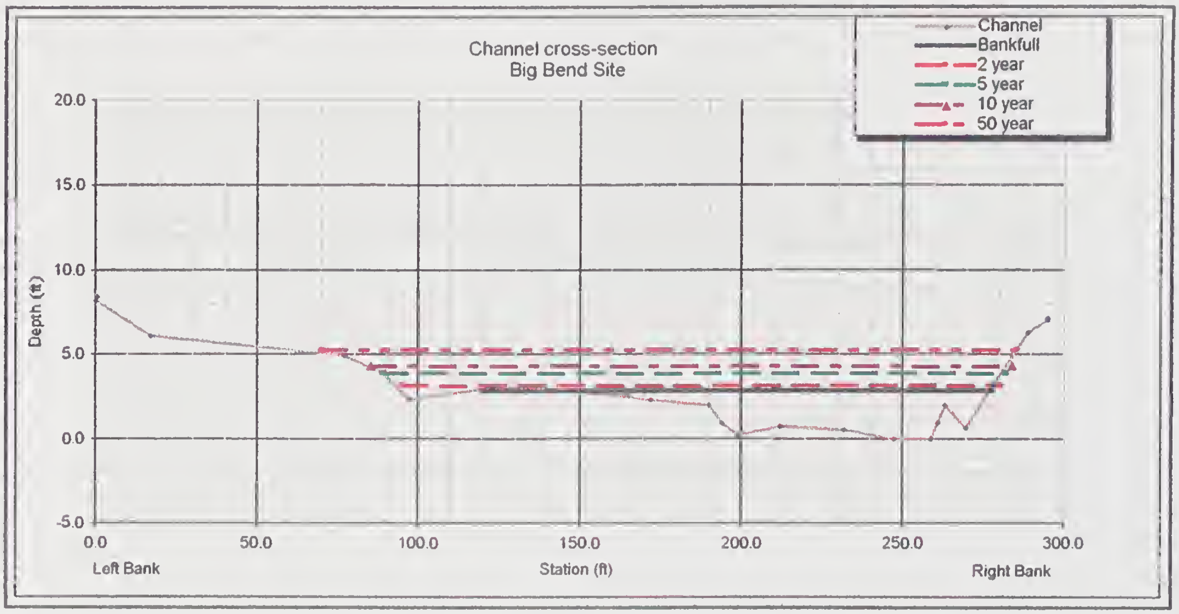
Narrows & Hereford Sites

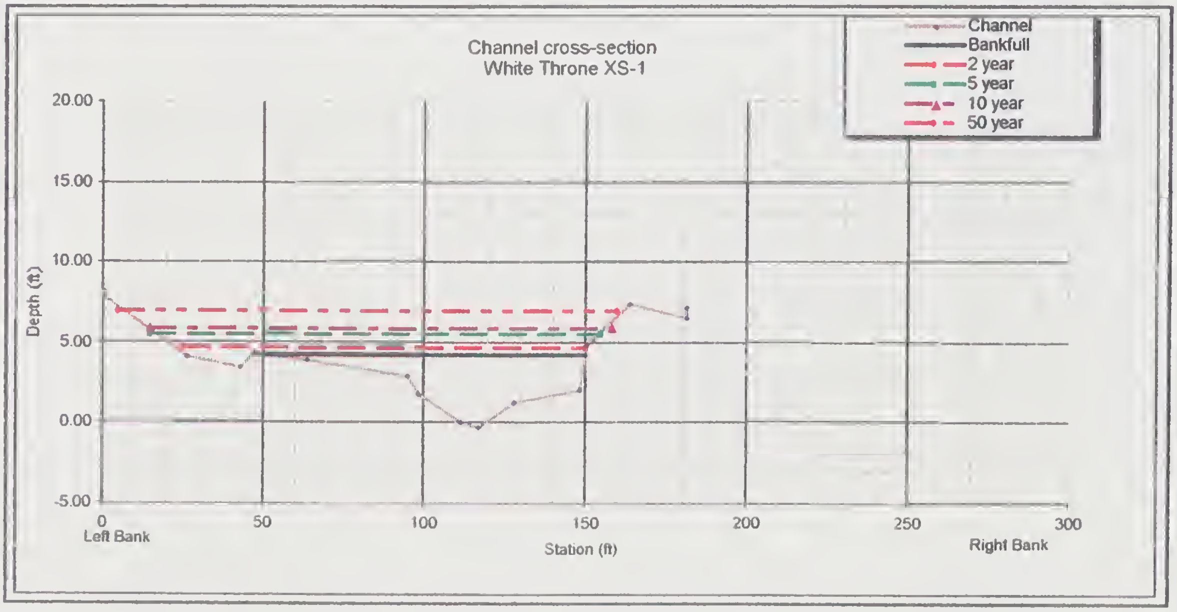




BIG BEND REACH

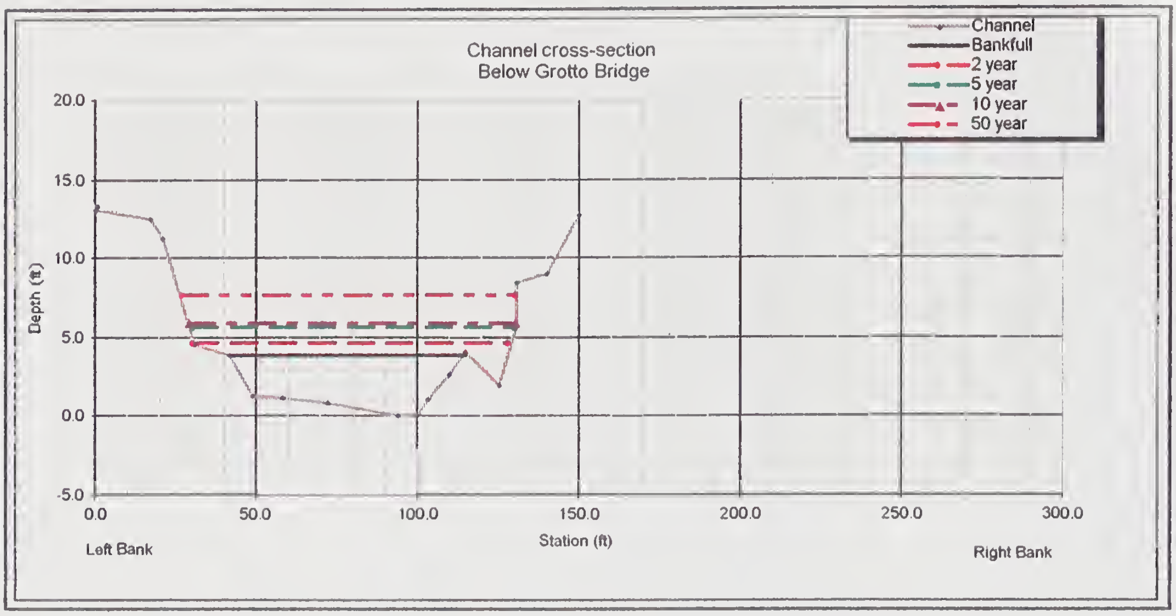
Big Bend and Great White Throne Sites





ZION LODGE REACH

Grotto Site



BIRCH CREEK REACH

Meander Site